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Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing

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NEWPORT

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PREFACE

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14. ABSTRACT. The United States Department of the Navy is required to assess impacts of Navy-generated sound in the water on protected marine species in compliance with applicable laws and regulations. This report applies to all of the Navy's Phase III Study Areas as described in each Environmental Impact Statement/ Overseas Environmental Impact Statement and describes the methods and analytical approach to quantifying the number of potential effects to marine mammals and sea turtles as a result of the Navy's at-sea training and testing. The Navy Acoustics Effect Model (NAEMO) serves as the primary data entry point for Navy activity information and as a repository for modeling output and estimated effects. The Navy used specific information about environmental conditions, best available marine mammal and sea turtle data, and projected Navy activities within each Study Area to run NAEMO. To account for mitigation for marine mammals and sea turtles, the Navy applies mitigation effectiveness factors to NAEMO output to conservatively quantify the potential for mitigation to reduce model-estimated exposures. Potential for avoidance, range to effects, and guild and stock breakouts are also discussed to present a comprehensive overview of the methods to quantify acoustic impacts on marine mammals and sea turtles.

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Navy Acoustics Effect Model (NAEMO), Acoustic modeling, Marine Mammals, Sea Turtles

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LIST OF ABBREVIATIONS AND ACRONYMS

AFTT	Atlantic Fleet Training and Testing
ASW	Antisubmarine Warfare
BRF	Behavioral Response Function
CASS	Comprehensive Acoustic Simulation System
EIS	Environmental Impact Statement
FFT	Fast Fourier Transform
GRAB	Gaussian Ray Bundle
HF	High-Frequency
HSTT	Hawaii- Southern California Training and Testing
HYCOM	Hybrid Acoustic Coordinate Ocean Model
IFFT	Inverse FFT
LF	Low-Frequency
MF	Mid-Frequency
NAEMO	Navy Acoustic Effects Model
NMFS	National Marine Fisheries Service
NMSDD	Navy Marine Species Density Database
NUWC	Naval Undersea Warfare Center
OAML	Ocean and Atmospheric Master Library
OEIS	Overseas Environmental Impact Statement
PTS	Permanent Threshold Shifts
REFMS	Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects
RMS	Root-Mean-Square
SEL	Sound Exposure Level
SPL	Sound Pressure Level
SWFSC	Southwest Fisheries and Science Center
TNT	Trinitrotoluene
TTS	Temporary Threshold Shifts
U.S.	United States
VACAPES	Virginia Capes

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1. INTRODUCTION

The United States (U.S.) Department of the Navy is required to assess potential impacts of Navy-generated sound in the water on protected marine species in compliance with applicable laws and regulations, including the National Environmental Policy Act, Executive Order 12114, the Marine Mammal Protection Act, and the Endangered Species Act. This report applies to all of the Navy's Phase III Study Areas as described in each Environmental Impact Statement (EIS)/ Overseas Environmental Impact Statement (OEIS) and describes the methods and analytical approach to quantifying the number of potential effects to marine mammals and sea turtles as a result of the Navy's at-sea training and testing.

The Navy has invested considerable effort and resources analyzing the potential impacts of underwater sound sources (i.e., impulsive and non-impulsive sources on marine mammals and sea turtles). Research on various methodologies, collaboration with subject matter experts, and a review by the Center for Independent Experts have led to the Navy's refinement of a standard Navy model for assessing the impacts of underwater sound, the Navy Acoustic Effects Model (NAEMO).

NAEMO is used to assess the level of behavioral disturbance and physiological impacts (e.g., temporary and permanent threshold shifts (TTS) and PTS), respectively)) predicted for individual marine mammals and turtles likely to be in the vicinity of Navy training and testing activities. The Navy then applies factors to account for animals that would avoid high level sound exposures (e.g., TTS or PTS) since these levels are greater than those that may cause a behavioral reaction, which in most cases would include moving away from the sound source (DeRuiter et al., 2013; Southall et al., 2012). The Navy also accounts for mitigation measures designed to avoid marine mammal and sea turtle exposure to explosives and high-intensity sound. Predicted impacts are then assigned to the marine mammal stocks that are present in the area to assess potential impacts at the stock level.

The predicted impacts are stored and examined in spreadsheets via pivot tables, charts, and graphs. Output shows the types of impacts predicted for each Navy training and testing activity by area, season, and species. To summarize and report, predicted impacts for each species and stock are summed across all of the projected activities (training and testing are summed separately) and then rounded to the nearest integer.

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2. NAVY ACOUSTIC EFFECTS MODEL OVERVIEW

NAEMO serves as a data entry point for Navy activity information and as a repository for modeling output and estimated effects. NAEMO consists of modules accessed via a graphical user interface. Navy training and testing activities were defined in NAEMO as scenarios with specific platforms, sources, targets, and military expended materials. Scenarios were further refined into events which also accounted for location and frequency of events. Section 3 describes the data inputs to NAEMO and Section 4 describes the implementation and outputs from each of the NAEMO modules.

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3. DATA INPUTS

The Navy used specific information about environmental conditions, best available marine mammal and sea turtle data, and projected Navy activities within each Study Area to run NAEMO and quantify potential impacts to marine mammals and sea turtles. Environmental data include information about bathymetry, seafloor composition (e.g., rock, sand), and factors that vary throughout the year such as wind speed and underwater sound speed profiles. Marine mammal and sea turtle data include densities, group sizes, and dive profiles. Lastly, the details of Navy training and testing activities were collected, which included location, rate of occurrence, and source characteristics.

3.1 Navy Training and Testing Activities

NAEMO uses a hierarchy to group Navy training and testing events for analysis. The broadest category includes the primary mission areas (e.g., air warfare, amphibious warfare, etc.). The activities that fall within these categories are further refined in NAEMO as “scenarios” which include data on the number of platforms, types and numbers of impulsive and non-impulsive sources, and source duration. Scenarios are then further defined as “events,” which include details on location and frequency of occurrence. This section also provides additional information on how scenario and event definitions are implemented in NAEMO.

3.1.1 Locations and Modeling Areas

Activities were modeled in range complexes, testing ranges, pierside locations, transit lanes, and other representative areas where training or testing may occur. Location restrictions were incorporated when applicable (i.e., minimum or maximum depth and distance from shore).

3.1.2 Platforms

Platforms include aircraft, submarines, surface ships, unmanned vehicles, and stationary structures (e.g., moored platforms). Typical platform speed and depth are accounted for in NAEMO. The number and types of platforms that participate in a given scenario can vary due to numerous factors, including deployment schedules, number of ships assigned to a strike group, specific testing objective, and planned or unplanned maintenance of ships and systems. The quantitative modeling uses the average number of platforms that would be used during a typical scenario. For example, if three-to-five surface ships normally participate in a given antisubmarine warfare exercise, the representative modeling scenario for this event would consist of four surface ships. The composition of this exercise represents the average number of antisubmarine warfare-equipped ships and types of sonar that would be used during a typical antisubmarine warfare exercise.

3.1.3 Sources

Acoustic sources were divided into two categories, impulsive and non-impulsive. Impulsive sounds feature a rapid increase to high pressures, followed by a rapid return to static pressure. Impulsive sounds are often produced by processes involving a rapid release of energy or mechanical impacts (Hamernik & Hsueh, 1991). Explosions and air gun impulses are examples of impulsive sound sources. Non-impulsive sound sources include sonar and other transducers, which lack the rapid rise time of impulsive sources and can have durations longer than those of impulsive sounds.

In addition to impulsive and non-impulsive, sources can be categorized as either broadband (producing sound over a wide frequency band) or narrowband (where the energy is within a single one-third octave band). Typically, broadband is equated with impulsive sources, and narrowband with non-impulsive sources, although non-impulsive broadband sources, such as acoustic communications equipment and certain countermeasures, were also modeled. All non-impulsive sources were modeled using the

geometric mean frequency. All impulsive sources were modeled using the time series of the pressure amplitude, including air guns.

3.1.3.1 Non-Impulsive Source Classes

Hundreds of common Navy sources were compiled into NAEMO in the Navy Sound Source Data file. These were reduced to the active sources that were applicable to quantitative modeling. These include explosive and non-explosive impulsive sources and non-impulsive sources (sonar and other transducers). Explosive impulsive sources were placed into bins based on net explosive weights. Each non-explosive impulsive source was assigned its own unique bin. Non-impulsive sources were grouped into bins that were defined in accordance with their fundamental acoustic properties such as frequency, source level, beam pattern, and duty cycle. Each bin was characterized by the most conservative parameters for all sources within that bin. Specifically, bin characteristics for non-impulsive sources were selected based on (1) highest source level, (2) lowest geometric mean frequency, (3) highest duty cycle, and (4) largest horizontal and vertical beam patterns**.** The specific source class bins proposed for use and the total annual usage under each alternative are provided in the EIS/OEIS.

The use of source classification bins provides the following benefits:

- Provides the ability for new sensors or munitions to be covered under existing authorizations, as long as those sources fall within the parameters of a "bin;"
- Allows analysis to be conducted in a more efficient manner, without any compromise of analytical results;
- Simplifies the source utilization data collection and reporting requirements anticipated under Marine Mammal Protection Act authorizations;
- Ensures a conservative approach to all impact estimates, as all sources within a given class are modeled at the lowest frequency, highest source level, longest duty cycle, or largest net explosive weight within that bin; and
- Provides a framework to support the reallocation of source usage (hours/explosives) between different source bins, as long as the total numbers of takes remain within the overall analyzed and authorized limits. This flexibility is required to support evolving Navy training and testing requirements, which are linked to real-world events.

Some sources are removed from quantitative analysis because they are not anticipated to result in takes of protected species include those of low source level, narrow beamwidth, downward-directed transmission, short pulse lengths, frequencies above known hearing ranges of marine mammals and sea turtles, or some combination of these factors.

3.1.3.2 Impulsive Sources

The steep pressure rise that characterizes impulsive sources and their potential for structural injury are the reason they are evaluated differently than are non-impulsive ones. Impulsive sources are further classified into explosive and non-explosive impulsive sources.

The following terms were used to collect data on impulsive sources:

1. <u>Source Depth</u>—the depth at which an impulse source goes off.
2. <u>Net Explosive Weight</u>—for explosive sources, the TNT equivalent weight of explosive material in the source.
3. <u>Source Signature</u>—the pressure time series of the source at a nominal distance of 1m. The explosive signatures are taken from the similitude equations (equations 3–5) based on net explosive weight, whereas the non-explosive signatures are taken from real-world data.

4. Cluster Size—the number of rounds fired (or buoys dropped) within a very short duration.
5. Count—the number of sources or clusters of sources deployed during a scenario.

Explosive impulsive sources include the following types of devices: mines, mine countermeasure systems, projectiles, rockets, missiles, bombs, explosive torpedoes, underwater demolition explosives, ship shock trial charges, impulsive sonobuoys, and littoral warfare line charges. A list and qualitative descriptions of impulsive sources can be found in the EIS/OEIS. Non-explosive impulsive sources include air guns and combustive sound sources.

3.1.3.3 Non-Impulsive Sources

Non-impulsive sources are sonars and other transducers and include the following types of devices: submarine sonars, surface ship sonars, helicopter dipping sonars, torpedo sonars, active sonobuoys, countermeasures, underwater communications, tracking pingers, unmanned underwater vehicles and their associated sonars, and other devices. Qualitative descriptions can be found in the EIS/OEIS.

The following terms were used to collect data on non-impulsive sources:

1. Source Depth—the depth at which a source goes active.
2. Source Level—the sound level of a source at a nominal distance of 1m, expressed in decibels referenced to one micropascal (dB re 1 µPa).
3. Nominal Frequency—typically, the geometric mean of the frequency bandwidth.
4. Source Directivity—the source beam was modeled as a function of a horizontal and a vertical beam pattern.
    a. The horizontal beam pattern was defined by two parameters:
        i. Horizontal Beamwidth—the width of the source beam in degrees measured at the 3-decibel (dB) down points in the horizontal plane (assumed constant for all horizontal steer directions).
        ii. Relative Beam Angle—the direction in the horizontal plane that the beam was steered relative to the platform’s heading (direction of motion) (typically 0°).
    b. The vertical beam pattern was defined by two parameters:
        i. Vertical Beamwidth—the width of the source beam in degrees in the vertical plane measured at the 3-dB down points (assumed constant for all vertical steer directions).
        ii. Depth/Elevation Angle—the vertical orientation angle relative to the horizontal.
5. Ping Interval—the time in seconds between the start of consecutive pulses for a non-impulsive source.
6. Pulse Length—the duration of a single non-impulsive pulse, specified in milliseconds. Duty cycle is defined as ping interval/ pulse length.
7. Signal Bandwidth—The geometric mean frequency is the square root of the product of the frequencies defining the frequency band (equation 3-1),

$$f_{gm} = (f_{min} \times f_{max})^{0.5}, \qquad (3\text{-}1)$$

where, f_{max} is the upper cutoff frequency and f_{min} is the lower cutoff frequency.

Many of these system parameters are classified and cannot be provided in an unclassified document. Each source was modeled utilizing representative system parameters based on the non-impulsive source category within which it occurs.

3.2 Physical Environment Data

The physical environment data described below play an important role in the acoustic propagation used in the modeling process. Since accurate *in-situ* measurements cannot be used to model activities that occur in the future, historical data are used to define a typical environmental state for propagation analysis. Because acoustic activities rely heavily on the accuracy of propagation loss estimates, the Navy has invested heavily in measuring and modeling the relevant environmental parameters. The results of this effort are databases with global measurements of these environmental parameters that comprise part of the Oceanographic and Atmospheric Master Library (OAML; Table 3-1). The distribution of OAML data is restricted to organizations within the Department of Defense and its contractors. The versions of the OAML databases within NAEMO are provided in Table 3-1. In order to capture environmental variability, NAEMO extracts information from the databases discussed below every 5 km along transects radiating out from each source location.

Table 3-1. Oceanographic and Atmospheric Master Library Environmental Databases

Parameter	Database
Bathymetry	Digital Bathymetric Database Variable-Resolution Version 5.4 (Level 0)
Seafloor Composition	Re-Packed Bottom Sediment Type Version 2.0 (includes High-Frequency Environmental Acoustics Version 1.0)
	Low-Frequency Bottom Loss Version 11.1*
	High-Frequency Bottom Loss Version 2.2*
Wind Speed	Surface Marine Gridded Climatology Version 2.0
Sound Speed Profile	Navy Hybrid Acoustic Coordinate Ocean Model (HYCOM) Version 2.2

*Low-frequency and high-frequency bottom loss databases are used to capture the variability of bottom sediment to absorb or reflect energy from high-frequency and low-frequency sound sources.

3.2.1 Bathymetry

Bathymetry can affect sound propagation in a variety of ways. In a shallow area, an acoustic ray will have more interaction with the bottom which will absorb some of the sound energy. The slope of the seafloor determines the angle at which an acoustic ray will be reflected off the bottom. Within a typical modeling area, bathymetry tends to be the environmental parameter that tends to vary the most. It is not unusual for water depths to vary by an order of magnitude or more in these areas. Bathymetry was obtained at the highest resolution available, ranging from 0.05-2.0 arc-minutes. Since propagation loss is determined along paths radiating out from an analysis point, bathymetry was extracted radially to align with these paths.

3.2.2 Seafloor composition

Seafloor composition can affect acoustic propagation calculations. For example, a muddy bottom absorbs more energy and a rocky bottom reflects more energy. However, this factor's impact on propagation tends to be limited to waters on the continental shelf and the upper portion of the slope because sound is more likely to reach the bottom in these areas. The primary acoustic propagation paths in deep water do not usually involve any interaction with the bottom, whereas in shallow water, bottom loss variability can play a larger role. This is especially true if the sound speed profile directs all propagation paths to interact with the bottom. For each modeled area, bottom type and the associated geo-acoustic parameters were extracted in accordance with the guidelines specified in Table 3-2. These data were extracted at the highest available resolution of one degree.

Table 3-2. Geo-Acoustic Parameter Guidelines as a Function of Acoustic Source Frequency

Frequency (f)	Database
f < 1 kHz	Low-Frequency Bottom Loss
1 kHz ≤ f < 1.5 kHz	Low-Frequency Bottom Loss and High-Frequency Bottom Loss
1.5 kHz ≤ f < 4 kHz	High-Frequency Bottom Loss
f ≥ 4 kHz	Bottom Sediment Type

3.2.3 Wind Speed

All wind speed data were extracted from the Surface Marine Gridded Climatology data at the highest available resolution of one degree. Wind speed data are directly related to other environmental parameters, primarily the sound speed. For example, wind in a downward refracting environment would not likely create a significant change in results because of the relatively short propagation ranges characterized by minimal surface interaction. In the case of a surface duct with correspondingly long propagation ranges and associated surface interaction, however, wind speed could have significant impact on the resultant propagation ranges.

3.2.4 Sound Speed Profiles

Navy Hybrid Acoustic Coordinate Ocean Model (HYCOM) sound speed profile data consist of temperature, salinity, and depth. For each scenario, these data were extracted at the highest resolution, 0.08 arc-degrees, over the extent of the modeled area. The sound speed throughout the water column is calculated from temperature, salinity, and pressure with the Chen-Millero-Li sound speed equation (Chen & Millero, 1977).

The spatial variability of the sound speed profiles is generally minimal within the modeling areas. The presence of a strong oceanographic front, in which temperature and salinity vary rapidly over a small geographic area, is a noteworthy exception to this rule. To a lesser extent, variability in the depth and strength of a surface duct can be of some importance to sound speed. In the mid-latitudes, the most significant variation in the sound speed profile is seasonal. For this reason, activities that occur year-round were modeled with two or four seasons, depending on the Study Area.

An example sound velocity profile is shown in Figure 3-1, spaced 10 kilometers (km) along a single transect in the Virginia Capes Range Complex. In shallow water, sound velocity varies primarily with temperature and salinity. At greater depths the temperature is more uniform so increases in sound velocity are primarily due to increases in pressure.

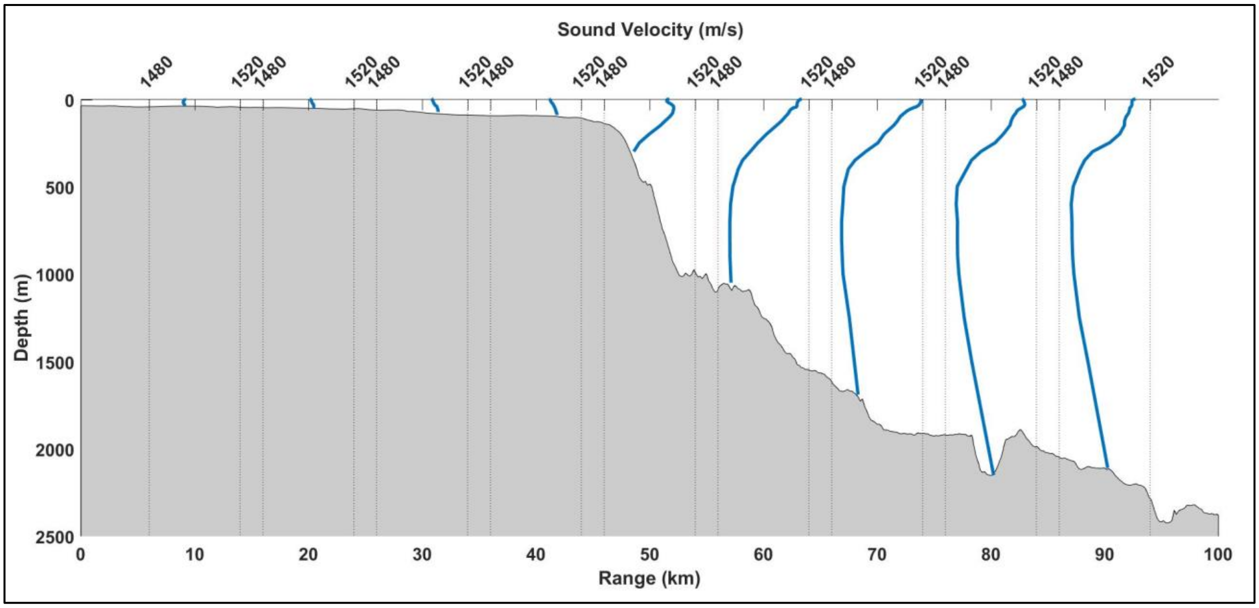

Figure 3-1. Sample Sound Speed Profile

3.2.5 Seasonal Definitions

The majority of Navy activities are not limited to a specific month or season. Therefore, most of the scenarios were modeled year-round. A seasonal approach was adopted to meet this requirement, given the impracticality of modeling each scenario for every month. The seasonal definitions that were employed were dictated by region and marine mammal and sea turtle presence (Table 3-3) as determined by the Density Technical Report (U.S. Department of the Navy, 2017a, 2017b). The seasonal averages were generated by linearly averaging the data for the months within a given season.

Table 3-3. Seasonal Definitions

Season		Dates
Warm	Summer	1 June – 31 August
	Fall	1 September – 30 November
Cold	Winter	1 December – 28/29 February
	Spring	1 March – 31 May

3.3 Marine Mammal and Sea Turtle Data

Marine mammal and sea turtle input data include density estimates, group sizes, dive profiles, and body masses. In NAEMO, marine species are represented by "animats," which are artificial or virtual animals used during modeling (Dean, 1998). Marine mammal densities were needed to estimate the number of animals of each species that may be present within a specific area and timeframe; therefore, the number of animals that could be affected by non-impulsive or impulsive activities. Details on the density data used for the Phase III analyses are provided in the Navy Marine Species Density Database (NMSDD) (U.S. Department of the Navy, 2017a, 2017b). Marine mammals and sea turtles are typically categorized by species in the NMSDD. NAEMO has adopted the same format for its results, with the exception of species that are grouped into guilds or stocks. In some cases, species can be difficult to distinguish from one-another during surveys at sea and are only reported as a group of similar species, or "guilds", which are processed in NAEMO as a species would be. The proportion of each species within each guild is

estimated based on sightings where species can be determined. Based on these proportions, predicted impacts to guilds are separated out to the species level. Similarly, many species within the study area are divided into multiple stocks based on life history and genetic stock structure for management purposes. Predicted impacts are assigned by stock when available, as opposed to the species as a whole.

3.3.1 Group Size

Many marine mammals are known to travel and feed in groups. NAEMO accounts for this behavior by incorporating species-specific group sizes into the animat distributions, and accounting for statistical uncertainty around the group size estimate. Group sizes were handled differently in each Study Area, based on data availability and the recommendations of the research groups that provided density information. For example, in the Atlantic Fleet Training and Testing (AFTT) Study Area, mean group sizes and the associated standard deviations were collected for each species via literature search. Mammals were distributed in groups of a size that varied according to an inverse Gaussian distribution defined by the group size mean and standard deviation. For the Hawaii-Southern California Training and Testing (HSTT) Study Area, simulations, group size mean, and standard deviation were collected from a combination of survey data from the Southwest Fisheries Science Center (SWFSC) and a literature review. The standard deviations were incorporated by randomly selecting a value from the poisson or lognormal distribution defined by the mean group size and standard deviation provided. The SWFSC also specified which species' group size followed a poisson distribution and which followed a lognormal.

3.3.2 Dive Profiles

NAEMO accounts for depth distributions by changing each animat's depth during the simulation process according to the typical depth pattern observed for each species. Dive profile information was collected via literature search. This information is presented as a percentage of time the animal typically spends at each depth in the water column. During a simulation, each animat's depth is changed every 4 minutes to a value randomly selected by the probability density function described by its profile. At this time, NAEMO does not simulate horizontal animat movement during an event.

3.4 Criteria and Thresholds for Assessing Impacts

Criteria and thresholds to assess impacts to marine mammals and sea turtles are synthesized from published study results. The Criteria and Thresholds for Assessing Acoustic and Explosive Impacts to Marine Mammals and Sea Turtles technical report (U.S. Department of the Navy, 2017c) provides details on the derivation of the Navy's current impact criteria. These criteria and thresholds are used to assess potential effects to marine mammals and sea turtles in the analysis process.

Upper and lower frequency limits will be used for each marine mammal hearing group and sea turtles so that sonar and other transducers with the majority of their energy above or below these limits would not be considered for acoustic effects to those species (Table 3-4).

Table 3-4. Lower and Upper Cutoff Frequencies for Marine Species Hearing Groups for Sonar and Other Transducers Used for Phase III Acoustic Analysis

Hearing Groups	*Limit (Hertz)*	
	Lower	*Upper*
Low-Frequency Cetaceans (Mysticetes)	5	30,000
Mid-Frequency Cetaceans	50	200,000
High-Frequency Cetaceans	100	200,000
Phocid Pinnipeds (In-Water)	50	80,000

Table 3-4. Lower and Upper Cutoff Frequencies for Marine Species Hearing Groups for Sonar and Other Transducers used for Phase III Acoustic Analysis (Cont'd)

Hearing Groups	***Limit (Hertz)***	
	Lower	***Upper***
Otariid Pinnipeds, Sea Otters, Polar Bears, Walruses, and Sirenians (In-Water)	20	60,000
Sea Turtles	5	2,000

Explosives, air guns, impact pile driving, and vibratory pile driving have significant acoustic energy within all group's hearing ranges; therefore, it is not necessary to apply frequency limits to these broadband sound sources.

4. NAVY ACOUSTIC EFFECTS MODEL

The following sections discuss the acoustic analysis, marine species distribution, simulation, and outputs from each of the NAEMO modules.

4.1 Acoustic Analysis

In NAEMO, the Acoustic Builder module generates propagation data. First, it uses event definitions from NAEMO to extract source characteristics and environmental data for a given location. It then uses a standard resolution for a set of propagation analysis points in the event's location (e.g., 0.1 degree in the AFTT Study Area). For each analysis point, the Navy's standard propagation model (the Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS)/(GRAB)) is run to generate a sound field for each source in the scenario. For non-impulsive sources the sound field data are saved in NAEMO and subsequently provided as input to Scenario Simulator. For impulsive sources CASS/GRAB is used to calculate several sound metrics which are provided to Scenario Simulator as input.

4.1.1 Comprehensive Acoustic Simulation System/ Gaussian Ray Bundle

The CASS/GRAB propagation model was used for all impulsive and non-impulsive modeling. Detailed descriptions of the CASS/GRAB model and its governing equations can be found in Keenan and Gainey (2015); and Weinberg and Keenan (1996).

The CASS/GRAB model is used to determine the propagation characteristics for acoustic sources with frequencies greater than 150 Hertz (Hz). Keenan and Gainey (2015) described CASS as "a linear acoustics, range-dependent, ray-based eigenray model that calculates arrival structure, sound pressure, reverberation, signal excess, and probability of detection." It has been accepted as the Navy standard and Ocean and Atmospheric Master Library (OAML)-certified model for active sonar analysis between 150 Hz and 500 kHz. For impulse modeling CASS/GRAB is used for frequencies as low as 25 Hz. Though it is not OAML approved for this frequency, Weinberg and Keenan (1996) showed that CASS/GRAB predicted the general trend of propagation loss well compared to other propagation loss models.

NAEMO analyses use CASS in the passive propagation mode, that is, one-way propagation, rather than the active mode, which uses two-way propagation. CASS uses acoustic rays to represent sound propagation in a medium. As acoustic rays travel through the ocean, their paths are affected by mechanisms such as absorption, reflection, and reverberation, including backscattering, and boundary interaction. The CASS model determines the acoustic ray paths between the source and a particular location in the water. The rays that pass through a particular point are called eigenrays.

GRAB's role in the propagation model is to group eigenrays into families based on their surface/bottom bounce and vertex history (Figure 4-1). For example, a ray that bounces off the surface and then off the ocean floor would be in a different family than a ray that bounces off the floor first and then the surface. Rays with no boundary interaction would be in yet another family. Once the eigenrays have been grouped into families, the ray path properties are integrated (source angle, arrival angle, travel time, phase, and amplitude) to determine a representative ray for each family. These properties are weighted prior to integration so that rays closer to the desired target depth have more weight. Each representative eigenray, based on its intensity and phase, contributes to the complex pressure field, and hence, to the total energy received at a point. The total received energy at a point is calculated by summing the modeled eigenrays. Figure 4-2 shows the representative eigenrays for the families shown in Figure 4-1. The total received energy at the receiving point (50 m depth, 1.4 km range) is calculated by summing the representative eigenrays. CASS/GRAB accommodates surface and bottom boundary interactions, but does not account for side reflections that would be a factor in a highly reverberant

environment, such as a depression or canyon, or in a man-made structure, such as a dredged harbor. Additionally, as with most other propagation models except finite-element-type models, CASS/GRAB does not accommodate diffraction or the propagation of sound around bends.

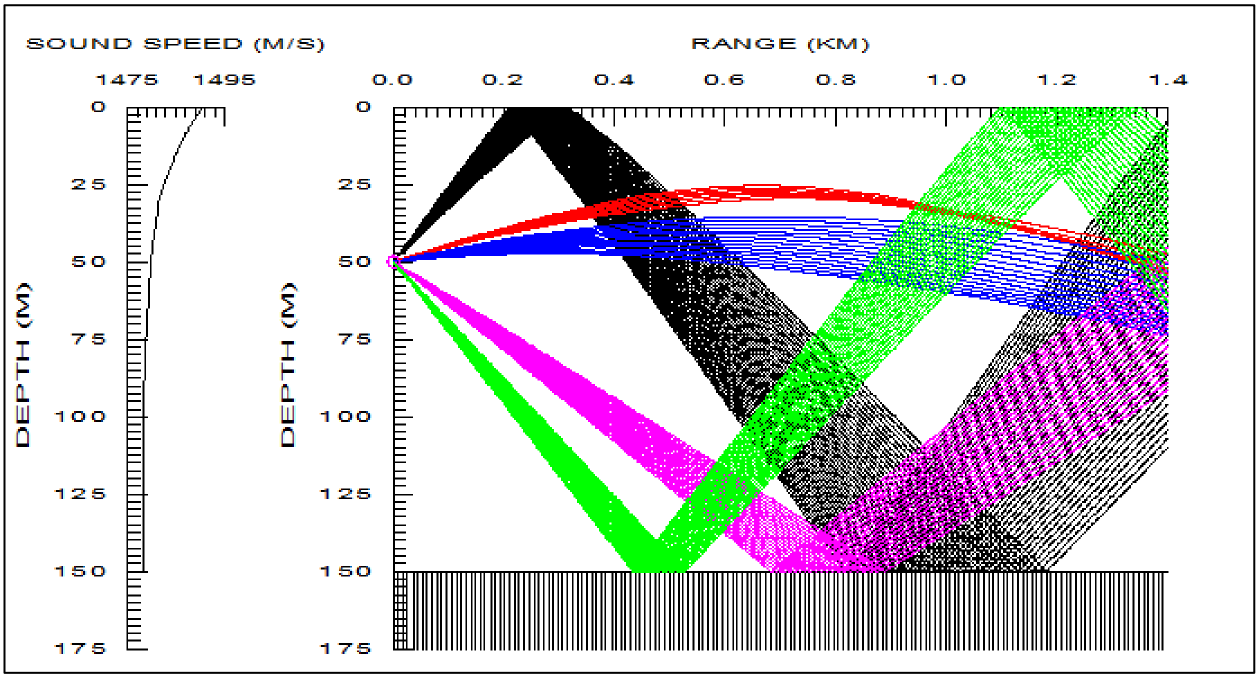

Figure 4-1. Colors Represent Distinct Families of Eigenrays Identified by GRAB

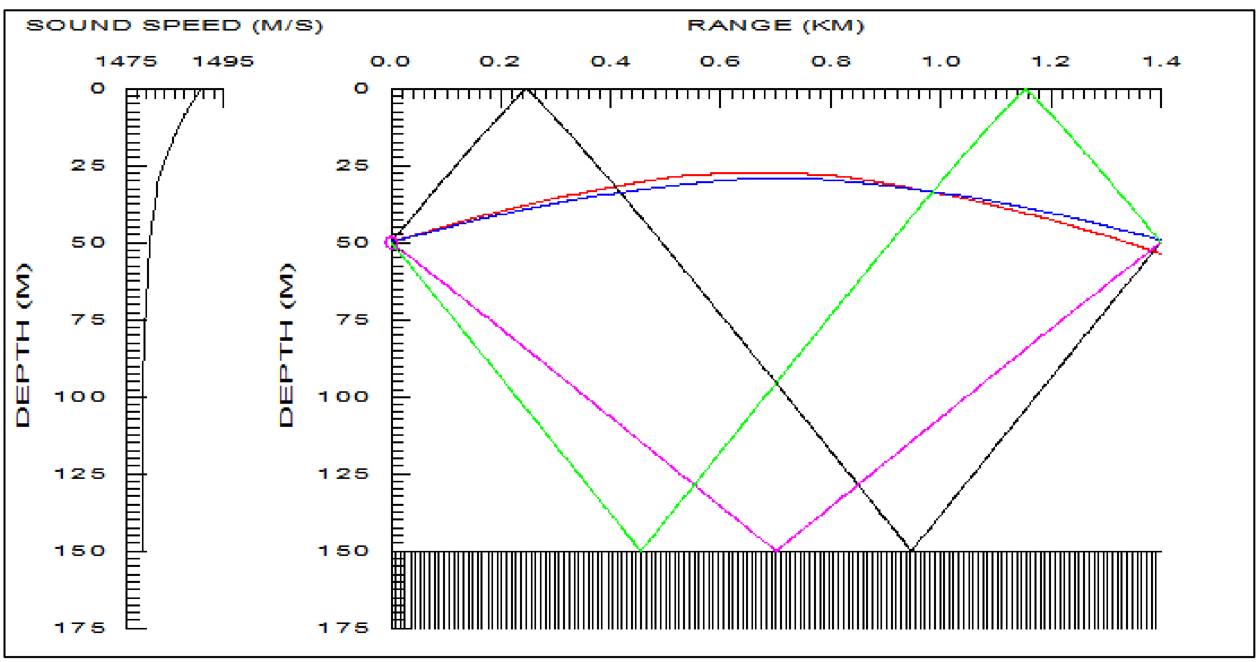

Figure 4-2. Representative Eigenrays for the Ray Families in Figure 4-1

CASS/GRAB generates a table of depth range points with an associated received level per location and per source. For non-impulsive sources, these received levels are used as input into Scenario Simulator

(Section 4.3.2), whereas for impulsive sources, further transformations are required, as described in Section 3.1.3.2.

CASS/GRAB is the most practical model to use for impulsive analysis. In order to evaluate some of the necessary metrics for explosives, a pressure time series is needed. The only other range-dependent models that can provide time information are so computationally intensive that given the number of computations required it would take too long to complete the analysis. For Phase II impulsive modeling, the Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects (REFMS) model was used. Though it was range-independent and not OAML-certified, REFMS was the best available model at the time. CASS/GRAB is a more logical model to use because it does not have these issues. Additionally the impulse model using CASS/GRAB has compared favorably with data (Deavenport & Gilchrest, 2015), though it should be noted that the data were for small explosives at short ranges. Data for large explosions and long ranges are needed to fully validate the model.

4.1.2 Non-Impulsive Model

The following features were included in Acoustic Builder for non-impulsive events:

- Events can be visually inspected and verified before modeling begins. For example, Acoustic Builder allows the user to view an event's geographic location, range complex, platforms, sources, bathymetry, modeling boxes, and local species distributions.
- Users can select analysis points to be run by CASS/GRAB. This can be done automatically by giving Acoustic Builder spacing between points, which it uses to create a grid of equally spaced analysis points. Or, users can manually select analysis points.
- Acoustic Builder provides a graphical user interface for CASS/GRAB and runs the propagation model at every analysis point selected.
- Acoustic propagation is run along 18 equally spaced radials (bearing angles) from an analysis point to 100 km, or until the received level has reached 100 dB.

4.1.3 Impulsive Model

The impulsive model used in the Navy's current analysis described in this report is an upgrade from previous modeling efforts. The model uses CASS/GRAB to create a frequency band-limited transfer function that is combined with a similitude source signature to obtain a pressure time series. Advantages of using CASS/GRAB over REFMS include:

- CASS/GRAB is OAML approved, REFMS is not.
- CASS/GRAB can vary environmental parameters with range, more accurately representing the environment.
- CASS/GRAB has a built in absorption model.
- CASS/GRAB is more numerically stable.

The impulsive model used in the Navy's current analysis described in this report is OAML improved. The impulsive model uses five metrics to describe the sound received by animats: peak sound pressure level ($\mathrm{SPL_{peak}}$) , root mean square sound pressure level ($\mathrm{SPL_{rms}}$), sound exposure level (SEL), calf impulse, and adult impulse. Sound pressure level (SPL) is the logarithm of the ratio of sound pressure to a relative pressure. The peak sound pressure level is the maximum SPL over time. The root-mean-square (RMS) pressure level is an average SPL over the duration of the signal. The ($\mathrm{SPL_{rms}}$) criteria are only applied to airguns. Sound exposure level represents both the SPL of a sound as well as its duration. Impulse is the integral of positive pressure over a brief time period. Impulse is a function of animat mass and is calculated for both calf and adult. The impulse metric is only applied to explosive impulses.

The main difference between impulsive and non-impulsive modeling is that the impulsive signal is time-dependent, whereas the pressure field for non-impulsive sources is modelled as an instantaneous phenomenon (Deavenport & Gilchrest, 2015). This is because impulsive signals are time-dependent processes characterized by a rapid rise and subsequent fall in pressure. The time dependence is incorporated by using outputs from CASS/GRAB to build a transfer function, and convolving this with a similitude source signature as described below (Deavenport & Gilchrest, 2015).

The first step is to use eigenray information from CASS/GRAB to create a transfer function of the form:

$$H(\omega) = \sum_{n=1}^{N} A_n e^{i\omega\tau_n + i\phi_n} \tag{4-1}$$

where ω is frequency ($2\pi f$ in Hz), N is the number of arrival paths, A_n is the received level for path n in Pa, τ_n is the arrival time (s) of path n, and ϕ_n is the phase (rad) of path n. This transfer function represents the instantaneous pressure field of the impulse, transformed so that it can be convolved with the source signature. The frequency resolution is determined by the sampling rate (32,768 samples per second) and the longest arrival time. Additionally, it is approximated that the levels, arrival times, and phases are identical within 1/3 octave bins defined from 25-16,384 Hz. CASS/GRAB is run at each of these frequencies to get the necessary eigenray information. Before running CASS/GRAB, bottom loss tables are computed in each frequency domain defined in table 2.

Explosive source signatures are modeled by similitude equations (Friedlander, 1946);

$$P_{sim}(t) = P_m e^{-\left(\frac{t}{2\theta}\right)} \cdot \left(1 - \left(\frac{t}{2\theta}\right)\right), \tag{4-2}$$

where, P_m is the amplitude of the initial shock wave in *Pa*, θ is the time decay constant in *s*, and t is the time after the initial shock wave arrives in *s*. P_m and θ can be expressed by Swisdak (1978);

$$P_m = K \cdot \left(\frac{\sqrt[3]{W}}{r}\right)^{\alpha}, \tag{4-3}$$

$$\theta = K_2 \cdot \sqrt[3]{W} \cdot \left(\frac{\sqrt[3]{W}}{r}\right)^{\alpha_2}, \tag{4-4}$$

where, r is the distance from the source in *m*, W is the net explosive weight of TNT in kg, and coefficients (K, K_2, α, and α_2) are specific to a given explosive type. The signature is modeled as 1 m from the source. The length of the signal is assumed to be 50ms, to ensure that all of the energy is accounted for. The pressure time series $P(t)$ is then determined by;

$$P(t) = \mathrm{IFFT}(\,H(\omega) \times \mathrm{FFT}(P_{sim}(t))) \times\ R^{-0.13}, \tag{4-5}$$

where, FFT and IFFT indicate the Fast Fourier Transform (FFT) and the Inverse Fast Fourier Transform (IFFT), and R is the slant range (the three-dimensional distance between the source and receiver). The $R^{-0.13}$ is a correction factor believed to account for the losses associated with energy dissipated at the shock front as well as the usual absorption losses associated with linear acoustics (Barash & Goertner, 1967; Deavenport & Gilchrest, 2015) also see Medwin and Clay (1977) in which similitude correction is attributed to “excess attenuation at the shock front.” This correction factor is specific to Trinitrotoluene

(TNT) and is not applied to non-explosive impulsive sources such as air guns. For the SEL calculation $P(t)$ is weighted by the auditory response function, which modifies the equation to;

$$P_w(t) = \text{IFFT}(\, M(\omega) \times H(\omega) \times \text{FFT}(P_{sim}(t))) \times \, R^{-0.13}, \tag{4-6}$$

where, $M(\omega)$ is the auditory weighting function for each hearing group. Calculation of the weighted and unweighted time series are intermediate steps in calculating the five previously mentioned metrics. The equation for the peak sound pressure level is given by:

$$\text{SPL}_{\text{peak}} = \, 20 \times \log\left(10^6 \times \max\big(P(t)\big)\right), \tag{4-7}$$

where, the 10^6 is multiplied by the pressure to convert to μPa, since the reference pressure is 1 μPa. The root mean square sound pressure is given by:;

$$\text{SPL}_{\text{rms}} = \, 20 \times \log\left(10^6 \times \sqrt{\frac{1}{t_u - t_l}\int_{t_l}^{t_u}[P(t)]^2 dt}\right), \tag{4-8}$$

where, t_l and t_u are chosen such that 90% of the sound energy is between t_l and t_u. The sound exposure level is the cumulative effect of the weighted sound energy for each hearing group, given by;

$$\text{SEL} = \, 10 \times \log\left(10^6 \times \int_0^{t_f}[P_w(t)]^2 dt\right), \tag{4-9}$$

where, t_f is the length of the received signal.

For explosive impulsive sources, the impulse is calculated for both adults and calves by:

$$I = \int_0^T P(t)dt \tag{4-10}$$

where T is determined by either the duration of the first positive impulse or 20% of the mammal's lung resonance period (Goertner, 1982). Between these two estimates, NAEMO selects whichever time period is shorter. The formula for the 20% lung resonance period of a mammal can be derived under the following three assumptions:

- The excitation of the lung cavity is approximated by the radial oscillation response of an equal volume spherical air bubble in water subjected to the same pressure wave.
- The lung volume in liters is 3% of the mass of the animal in kilograms.
- As the animal dives the lungs undergo isothermal compression.

These assumptions lead to the following formula for the 20% lung resonance:

$$T = \sqrt{\frac{\rho}{3\gamma}} \times \frac{(1.8 \times 10^{-4}\pi^2 M P_1)^{1/3}}{{P_0}^{5/6}}, \tag{4-11}$$

where, ρ is the density of water, γ is the adiabatic exponent for air, M is the animal mass, P_1 is the atmospheric pressure, and P_0 is the hydrostatic pressure (Goertner, 1982).

Propagation for impulsive sources is run along 9 equally spaced radials from an analysis point to 30 km. The range is extended to 100 km if any of the metrics are still above threshold at 30 km. Each of the above metrics are summarized into tables for each bearing, range, and depth to be used in the impulsive simulator.

4.2 Marine Species Distribution Builder

Marine mammals and sea turtles are distributed into simulation areas, and multiple iterations (see Section 4.2) are run for each species to account for statistical uncertainty in the density estimates. Each iteration varies according to the standard error associated with the density estimate (U.S. Department of the Navy, 2017a, 2017b). The density data are provided as a geographic grid (typically 10 km x 10 km) in which each cell is assigned a species density (animals/km^2). One density grid for each species or guild was provided. In many cells, a standard deviation was provided with the density estimate. However, for areas where density predictions were made for non-surveyed areas, the density cells were so far away from any survey measurement that the estimated statistical uncertainty would not be meaningful. In these cases standard error was not provided. Group size and dive profiles were taken into account and are discussed in Sections 3.3.1 and 3.3.2. As described in Section 3.3, animats were used during modeling to function as a dosimeter, recording energy received from all sources that were active during a scenario.

The distribution of animats in NAEMO starts with the extraction of species density estimates from the NMSDD for a given area and month. In order to incorporate statistical uncertainty surrounding density estimates into NAEMO, 30 distributions were produced for each species for each season, each of which varied according to the standard deviations provided with the density estimates. The following steps are then taken to distribute the animats within the defined modeling space.

- In each cell, the density estimate for that iteration is determined by randomly selecting a single value from a distribution defined by the density estimate (the mean of the distribution) and its standard deviation. These definitions were determined specific to each Study Area (e.g., for the HSTT Study Area, a lognormal distribution was used; for the AFTT Study Area, a compound poisson-gamma distribution was specified in the density regression model). If the density estimate did not have a corresponding standard deviation, the density remained constant at the mean for every iteration.
- The density estimate (animals/km^2) for that iteration is multiplied by the cells' area (km^2) to obtain the total number of animats in that cell.
- The total number of animats in each cell is summed across the entire area to determine the total number of animats in the entire area.
- Animats are placed into groups according to mean and standard deviation of group size (see Section 3.3.1). Groups are created until total abundance is reached.
- Groups of animats are then distributed into cells according to the probability density function defined by the original density estimates provided.

These steps result in a series of data files containing the time, location, and depth of each animat placed within the modeling area. The standard deviation was only used to vary the total number of animats in the entire region. This is necessary because, as a consequence of extrapolating the regression models into areas without survey measurements, the statistical uncertainty in these cells was substantially higher than in areas with survey measurements. An unrealistically high number of animats was often selected for these cells, which warped the population's spatial distribution.

4.3 NAEMO Simulation Process

The NAEMO simulation process combines all of these previously defined data and estimates the acoustic effects on marine mammals and sea turtles. The first module, Scenario Simulator, combines scenario definitions from Scenario Builder, data created in Acoustic Builder, and animat distributions created in Marine Species Distribution Builder to produce a record in NAEMO of the sounds received by each animat. The second module, Post Processor, reads the record created by Scenario Simulator, applies the frequency-based weighting functions, and conducts a statistical analysis to estimate effects associated with each marine mammal and sea turtle group based on the specified criteria thresholds. Results from each analysis are stored in NAEMO. The third and final module, Report Generator, provides a mechanism to assemble all of the individual species exposure records created by Post Processor and computes annual effect estimates. Estimated annual effects can be grouped by activity, season, and geographic region before outputting the results to comma-separated text files that can be used for further examination of the data. The following sections provide additional information for each module.

4.3.1 Monte Carlo Simulation Approach

Estimation of effects in NAEMO is accomplished through Monte Carlo simulations. This approach was chosen to account for the variability inherent in many factors of testing and training events such as platform location and movement, precise location of modeling area, and instantaneous distributions of marine mammals and sea turtles. Additionally, NAEMO incorporates individual animat movement vertically in the water column at a specified displacement frequency for sufficient sampling of the depth dimension. Individual animats are not moved horizontally within NAEMO. The location of an event is randomly selected within a specified modeling area. NAEMO uses unique iterations of the simulated animal populations in each simulation, which allows it to provide sufficient sampling in the horizontal dimensions for statistical confidence. Monte Carlo simulations also produce statistically independent samples, which allows for the calculation of metrics such as standard error and confidence intervals. Thirty Monte Carlo simulations are run per event, per species, and per season. In each simulation, the following factors are randomly selected:

- Modeling box (the area to which platforms are restricted)
- Geographic location of animats
- Depth of each animat (updated at 4 minute intervals during simulation)
- Platform start location within the modeling box
- Platform track (unless platform is stationary or its track is defined by waypoints)
- Time that sources first go active (unless timing is specified in scenario definition)

4.3.2 Scenario Simulator

The purpose of Scenario Simulator is to determine the level of sound received by each animat. This module references the scenario definition in NAEMO to determine the starting location, direction, and depth of each platform. Scenario Simulator then steps through time and interrogates each of the platform sources to determine which sources are actively emitting sound during that time step.

The simulation begins with a time equal to zero and progresses incrementally in 1-second steps until the end of the scenario. For each active source, the beam pattern area and direction of sound source emission is computed. The beam pattern area is calculated from the horizontal beam pattern and maximum propagation distance, which are stored in the source table in NAEMO. For example, the area for a source with a ninety-degree horizontal beam pattern and a maximum propagation distance of 100 km would equate to a quarter of a circle whose radius is 100 km. The beam pattern direction is based

on the direction of travel of the platform and any offsets defined for the horizontal beam pattern. The next step in the process identifies all animats that fall within each defined beam pattern area.

Propagation data are computed at multiple points within each modeling box to account for platforms moving during the simulation (Section 4.1). The exception to this is scenarios that involve only stationary platforms. At each time step, the position of each platform is compared to the locations of each propagation analysis point to determine the closest propagation file.

For each animat identified in the beam pattern, a lookup in the sound source propagation file is performed to determine the received sound level for that animat. The lookup is conducted based on the bearing and distance from the platform to the animat and the depth of the animat. The closest matching point within the propagation file is used.

Simulation output for each animat is stored in NAEMO. These outputs include simulation time, platform name, source name, source mode name, source mode frequency, source mode level, ping length, platform location (latitude/longitude), platform depth, species name, animal identification number, animal location (latitude/longitude), animal depth, animal distance from source, and sound received levels. A single animat may have one or more entries in the data file at each time step depending on the number of sources determined to be within hearing distance.

4.3.3 Post Processor

Post Processor uses output from Scenario Simulator to compute the impact of events on each marine mammal and sea turtle group. Criteria and thresholds (Section 0) are applied to Monte Carlo simulations which are then combined to provide a mean estimate of effects for each event.

4.3.3.1 Non-Impulsive Sources

For non-impulsive sources, Post Processor uses two metrics to describe sound received by animats, SPL and SEL. Post Processor computes maximum SPL and accumulated SEL over the entire duration of the event for each animat. The maximum SPL, which is used to determine behavioral effects, is simply the maximum received level reported in Scenario Simulator. Accumulated SEL is used to determine PTS and TTS, and represents the accumulation of energy from all time-steps and from multiple source exposures. For SEL, the appropriate auditory weighting functions defined by the marine mammal and sea turtle criteria (Section 0) are applied to adjust the received levels. SEL is given by;

$$\mathrm{SEL}_{s,t} = \mathrm{SPL}_{\mathrm{weighted},t} + 10 \times \log(PL_s), \tag{4-12}$$

where, s is source s, t is time t, $\mathrm{SPL}_{\mathrm{weighted},t}$ is the received level adjusted by the species auditory weighting function at time t, and PL_s is the pulse length of source s. The SEL values are then power summed across time to give a cumulative SEL for each source;

$$\text{Cumulative SEL}_s = 10 \times \log\left(\sum_{t=1}^{n} 10^{\mathrm{SEL}_{s,t}/10}\right) \tag{4-13}$$

where, n is the number of time steps for the given source. After these calculations, the cumulative SEL is once more power summed across sources for each animat to determine the final cumulative SEL. A mean number of SPL and SEL simulated exposures are computed for each 1-dB bin. The mean value is

based on the number of animats exposed at that dB level from each track iteration. The Behavioral Response Function (BRF) curve is applied to each 1-dB SPL bin to compute the number of behaviorally affected animats per bin. The number of behaviorally affected animats per bin is summed to produce the total number of behavioral effects.

Mean 1-dB bin SEL exposures are then summed to determine the number of instances in which PTS and TTS thresholds were exceeded. PTS values represent the cumulative number of animats affected at or above the PTS threshold. TTS values represent the cumulative number of animats affected at or above the TTS threshold and below the PTS threshold. Each animat can only be reported under a single criterion (e.g., once an animat is reported for PTS, it would not additionally be reported under TTS or behavioral). Behavioral effects are only computed for animats that experience two or more pulses.

4.3.3.2 Impulsive Sources

For impulsive sources five metrics are used to describe the sound received by animats: peak sound pressure level ($\mathrm{SPL_{peak}}$) , root mean square sound pressure level ($\mathrm{SPL_{rms}}$), SEL, calf impulse, and adult impulse. $\mathrm{SPL_{rms}}$ is only applied to airguns. Calf and adult impulses are only applied to explosive sources. SEL is a cumulative metric and is adjusted if a group of sources is in a cluster where c is the cluster size. This is then power summed over all clusters of sources to get the final cumulative SEL for the animat.

$$\mathrm{SEL}_c = \mathrm{SEL} + 10 \times \log(c) \tag{4-14}$$

Unlike non-impulsive sources, criteria for mortality and injury to animats is evaluated. Mortality and lung injury are determined by calf and adult impulse. Gastrointestinal injury is driven by ($\mathrm{SPL_{peak}}$). Both TTS and PTS have duel metrics: $\mathrm{SPL_{peak}}$ and SEL. Only one of these metrics needs to be above threshold to trigger TTS or PTS. Behavioral effects are based only on the SEL metric and are only computed for counts greater than one.

4.3.3.3 NAEMO Output

All scenarios analyzed in NAEMO were evaluated as single events occurring within a given season and location. Scenarios that occurred over multiple seasons and locations were modeled for each combination of season and location. The annual estimated effects for a single scenario are determined by taking the average of all seasons and locations modeled for that scenario. To create the average effects, each scenario was multiplied by a factor based on the number of seasons, locations, and events per season that scenario would be conducted. Each factored scenario effect is then summed together to produce the average scenario effect. Total annual effects resulting from all scenarios modeled are then the summation of each scenario's averaged effect.

Scenarios that may not occur every year are the exception to this methodology. Non-annual scenarios were modeled in multiple locations and seasons to provide coverage for all possible conditions, but these scenarios occur only one time within a given year. Therefore, the maximum effects from all modeled locations and seasons are used in place of the average values. To compute the maximum requires using a multiplication factor of one for each location and season and then determining the maximum per species effect from all locations and seasons.

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5. MITIGATION EFFECTIVENESS

The Navy implements mitigation to avoid potential impacts on biological and cultural resources. Procedural mitigation is tailored to each specific stressor or training and testing activity category, and involves: (1) the use of one or more trained Lookouts to diligently observe for specific biological resources within a mitigation zone during the activity, (2) requirements for Lookouts to immediately communicate sightings of applicable biological resources to the appropriate watch station for information dissemination, and (3) requirements for the watch station to implement mitigation (i.e., halting an activity, powering down sonar, or shutting down sonar) until recommencement conditions have been met. The Navy will implement procedural mitigation for activities whenever and wherever that activity takes place within the Study Area, as described in Chapter 5 (Mitigation) of each Phase III EIS/OEIS document.

Mitigation zones are designed to avoid injurious impacts on marine mammals and sea turtles and to the maximum extent practicable are measured as the radius from an acoustic, explosive, or physical disturbance and strike stressor (e.g., a ship hull, sonobuoy, pile driver, or vessel). The mitigation zone sizes represent the maximum range for which Lookouts can reasonably be expected to maintain situational awareness and visually observe for biological resources during typical at sea conditions, or the predicted average range to PTS.

Establishing a mitigation zone that extends out to the average range to onset of PTS also provides mitigation for the predicted average range to onset of mortality and onset of injury due to explosives. Because the mitigation zones are based off the acoustic bin with the largest range to effects within each stressor or activity category, the mitigation zones are even more protective during activities that use acoustic sources from lower source level bins. Furthermore, mitigation implementation will only be triggered by the sighting of an animal within a mitigation zone at or near the surface of the water; however, the benefits of implementing that mitigation will also extend to any animals that happen to be located at depth within the mitigation zone but were not available to be observed.

The Navy Acoustic Effects Model estimates acoustic and explosive effects without taking mitigation into account; therefore, the model overestimates predicted impacts on marine mammals and sea turtles within mitigation zones. To account for mitigation for marine mammals and sea turtles, the Navy conservatively quantifies the potential for mitigation to reduce model-estimated PTS to TTS for exposures to sonar and other transducers, and reduce model-estimated mortality to injury for exposures to explosives.

5.1 Mitigation Effectiveness Factors

The Navy quantitatively assessed the effectiveness of its mitigation measures on a per-scenario basis for four factors: (1) species sight ability, (2) a Lookout's ability to observe the range to PTS (for sonar and other transducers) and range to mortality (for explosives), (3) the portion of time when mitigation could potentially be conducted during periods of reduced daytime visibility (to include inclement weather and high sea state) and the portion of time when mitigation could potentially be conducted at night, and (4) the ability for sound sources to be positively controlled (e.g., powered down).

During the conduct of training and testing activities, there is typically at least one, if not numerous, support personnel involved in the activity (e.g., range support personnel aboard a torpedo retrieval boat or support aircraft). In addition to the Lookout posted for the purpose of mitigation, these additional personnel observe for and disseminate marine species sighting information amongst the units participating in the activity whenever possible as they conduct their primary mission responsibilities. However, as a conservative approach to assigning mitigation effectiveness factors, the Navy elected to

only account for the minimum number of required Lookouts used for each activity; therefore, the mitigation effectiveness factors may underestimate the likelihood that some marine mammals and sea turtles may be detected during activities that are supported by additional personnel who may also be observing the mitigation zone.

5.1.1 Species Sightability

The ability to detect marine mammals and sea turtles is dependent on the animal's presence at the surface and the characteristics of the animal that influence its sight ability. The Navy considered applicable data from the best available science to numerically approximate the sight ability of marine mammals and determined that the standard "detection probability" referred to as g(0) is most appropriate. This detection probability is derived from systematic line-transect marine mammal surveys based on species-specific estimates for vessel and aerial platforms. Estimates of g(0) are available from peer-reviewed marine species line-transect survey reports, generally provided through research conducted by the National Marine Fisheries Service (NMFS) Science Centers.

There are two separate components of g(0): perception bias and availability bias (Marsh & Sinclair, 1989). Perception bias accounts for marine mammals that are on the transect line and detectable, but were missed by the observer. Various factors influence the perception bias component of g(0), including species-specific characteristics (e.g., behavior and appearance, group size, and blow characteristics), viewing conditions during the survey (e.g., sea state, wind speed, wind direction, wave height, and glare), observer characteristics (e.g., experience, fatigue, and concentration), and platform characteristics (e.g., pitch, roll, speed, and height above water). To derive estimates of perception bias, typically an independent observer is present who looks for marine mammals missed by the primary observers and an estimate of the probability that animals are missed by the primary observers is determined. Availability bias accounts for animals that are missed because they are not at the surface at the time the survey platform passes by, which generally occurs more often with deep diving whales (e.g., sperm whale and beaked whale). The availability bias portion of g(0) is independent of prior marine mammal detection experience since it only reflects the probability of an animal being at the surface within the survey track and therefore available for detection.

Values for g(0) used by the Navy took both perception and availability bias into account when available, as well as the Beaufort sea state at the time of the survey when available. The studies used by the Navy performed vessel surveys (Barlow, 2015, 2016; Palka, 2006) and aircraft surveys (Carretta et al., 2000; Fuentes et al., 2015; Hain et al., 1999; Miller et al., 1998; Palka, 2006; Seminoff et al., 2014). Because these surveys are not able to be performed for all species in Navy study areas, species for which no g(0) value is available were assigned a surrogate species based on a variety of factors including morphology, group size, and behavior.

Similarities and differences do exist between the methodology used for line-transect surveys and for marine mammal and sea turtle detection by Navy Lookouts. Generally, there are two primary observers searching for animals during line-transect surveys; each primary observer looks for marine species in the forward 90-degree quadrant on their side of the survey platform and scans the water from the vessel to the horizon. In comparison, there are typically multiple Navy Lookouts in addition to other personnel (such as bridge watch personnel) that are scanning the water around the vessel and within the mitigation zone. Both observers on line-transect surveys and Navy Lookouts scan the water with the naked eye and are equipped with hand-held binoculars and oftentimes with pedestal mounted binoculars on larger vessels. Line-transect surveys and subsequent analyses are typically used to estimate cetacean and turtle abundance and are designed to cover the survey area uniformly (straight lines or grids) at a constant speed (generally 10 knots for vessels and 100 knots for aircraft). In comparison, Navy training and testing may occur in the same area or may be stationary, thereby

allowing Navy Lookouts more time to scan an area. This may also provide Navy Lookouts additional opportunities to sight animals if they were not at the surface or visible initially, and to re-sight animals. The speed that Navy vessels travel during training and testing is variable, as an example, a vessel with a hull-mounted sonar will typically travel between 10 and 15 knots when engaged in antisubmarine warfare training. Visual line-transect surveys for marine mammals and sea turtles used to derive g(0) are conducted during daylight (although at night, passive acoustic data may still be collected for marine mammals). Although observers may be required to collect data in high sea states up to Beaufort 6 and during periods of rain and fog, which may reduce marine mammal detections due to poor visibility (Barlow, 2006), surveys are typically scheduled for a season when weather at sea is likely to result in favorable sighting conditions. For some activities, Navy Lookouts observe for marine species in inclement weather, and in comparison to surveys, there is less control over when they observe for animals since they do so in all seasons and conditions and do not go off watch even in higher Beaufort sea states. Detection probability can be affected greatly by the sea state at the time of the observation for both line-transect surveys and Navy Lookouts. Surveyed observations made in less than ideal conditions are reflected in the values for g(0) (Barlow, 2003; Barlow & Forney, 2007).

Marine mammal and sea turtle detections along a transect during research surveys differ in both scope and purpose from Navy lookouts observing the water proximate to Navy training or testing activity. These differences were carefully considered when comparing the mitigation effectiveness to marine species surveys.[1] These differences suggest that the use of g(0) is a conservative approach that will underestimate the protection afforded by the implementation of mitigation. These differences are as follows:

- An observer is responsible for detecting marine mammals and sea turtles in their quadrant of the trackline out to the limit of the available optics. To implement mitigation, Navy Lookouts are responsible for detecting marine mammals or sea turtles in a mitigation zone (e.g., within 1,000 yd. from a ship transmitting active sonar).
- Although Navy Lookouts generally have less experience detecting marine species than observers used for line-transect surveys, Lookouts are trained using the NMFS-approved Marine Species Awareness Training. In addition, they do have significant experience looking for objects (including marine mammals) on the water’s surface to ensure the safety of ships and aircraft.
- A systematic marine species line-transect survey is designed to sample broad areas of the ocean, and generally does not retrace the same area during a given survey. Therefore, the two primary observers have only a limited opportunity to detect animals that may be present during a single pass along the trackline (e.g., deep-diving species may not be present at the surface as the survey transits the area). In contrast, many Navy training and testing activities involve area-focused events (e.g., anti-submarine warfare tracking exercise), where participants are likely to remain in the same general sea space during an event. In other cases Navy training or testing activities are stationary (i.e., pierside sonar testing or use of dipping sonar), which allow Lookouts to focus on the same area throughout the activity.
- In some cases, Navy events can involve more than one vessel or aircraft (or both) operating in proximity to each other or otherwise covering the same general area. Additional vessels and aircraft can result in additional watch personnel observing the mitigation zone (e.g. ship shock

[1] Barlow and Gisiner (2006) provide a description of typical marine mammal survey methods from ship and aircraft and then provide differences in detection of beaked whales between trained marine mammal observers and seismic survey mitigation, which is not informative with regard to Navy mitigation procedures.

trials). This would result in more observation platforms and observers looking at the mitigation zone than the two primary observers used in marine species surveys upon which g(0) is based.

The Navy recognizes that g(0) values are estimated specifically for line-transect analyses; however, g(0) is still the best statistically-derived factor for assessing the likely marine mammal and sea turtle detection abilities of Navy Lookouts. Based on the points summarized above, as a factor used in accounting for the implementation of mitigation, g(0) is considered to be the best available scientific basis for Navy's representation of the sight ability of a marine mammal or sea turtle as used in this analysis.

5.1.2 Ability to Observe the Mitigation Zone

In addition to species sight ability, another important factor in evaluating how effective Navy Lookouts will be at detecting marine species is to determine whether the Lookout will be able to visually observe the entire range to impact during the training or testing activity. The ability to observe the impact range could be compromised by certain characteristics of the observation platform or mitigation zone, such as the mitigation zone being located a far distance from the observation platform (e.g., during gunnery exercises involving the use of large-caliber munitions), type of platform(s), number of Lookouts, and size of the mitigation zone.

Observation Area = portion of impact range that can be continuously observed during an event (5-1)

- Area observable was derived by analyzing the types of platforms utilized and the objectives of training and testing scenarios to determine the opportunities and capabilities that participants had to observe the impact range.
- If the entire impact range can be continuously visually observed, then *Observation Area* = 1.
- If over half of the impact range can be continuously visually observed, then *Observation Area* = 0.5.
- If less than half of the impact range can be continuously visually observed, then *Observation Area* = 0. Therefore, mitigation is not factored into the acoustic effects analysis of that event. In reality, however, some protection from applied mitigation measures would be afforded during these activities, even though it is not accounted for in this quantitative analysis.

5.1.3 Periods of Reduced Visibility

The next factor in evaluating how effective Lookouts will be at detecting marine species is to determine whether the event could be conducted during periods of reduced visibility, such as during periods of rain, high wind, high sea state, or at night. If the event could be conducted during periods of low visibility, then the effectiveness was reduced by the sum of the individual visibility reduction factors. This is a conservative assumption because even events that could possibly occur during periods of low visibility would likely typically take place during periods of good visibility. Although activities that occur at night under certain moon phases (e.g. full) could result in clear nighttime visibility, this was not accounted for in the analysis structure.

Visibility = 1 – sum of individual visibility reduction factors (5-2)

- Periods of reduced visibility were derived from data input into the Navy's Acoustic Effects Model database by training and testing stakeholders.
- The percentage of time that an activity could occur at night would result in a *visibility reduction factor* = 0, 0.25, or 0.50
- If the event could occur in high sea state (Beaufort sea state of 4 or higher), then *visibility reduction factor* = 0.25

- If the event could occur in fog, rain, or high wind, then *visibility reduction factor* = 0.25
- If an event could occur in high sea state and fog, rain, or high wind, the visibility reduction factor was not summed to equal 0.50. To avoid doubling the reduction in visibility from inclement weather on the whole, the maximum reduction factor due to high sea state and fog, rain, and high wind is 0.25.

5.1.4 Positive Control of Sound Sources and Explosives

The final factor helps evaluate how effective mitigation will be based on the sound source's ability to be positively controlled in response to a marine species sighting in the mitigation zone. Sound transmissions from most sonar and other transducers can be ceased within a few seconds after the operator has been notified of an animal sighting in the mitigation zone. Other sound sources are not positively controlled, such as explosives using a diver-placed time-delay firing devices (i.e., the detonation cannot be terminated once the fuse is initiated due to human safety concerns).

Positive Control = positive control factor of all sound sources involving mitigation (5-3)

- Positive control of sound sources and explosives was derived from data input into the NAEMO database by training and testing stakeholders.
- If all sound sources involving mitigation are under positive control, then *Positive Control* = 1
- If all sound sources involving mitigation are not under positive control, then *Positive Control* = 0
- If most sources within a scenario involving mitigation are under positive control, with the exception of one source (e.g., torpedo), then *Positive Control = 0.5*

5.2 Quantifying Mitigation Effectiveness

The Navy used the equations in the below sections to calculate the reduction in model-estimated mortality impacts due to implementing mitigation.

$$\text{Mitigation Effectiveness} = \text{Species Sightability } [0\text{–}1] \times \text{Visibility } [0.25, 0.5, 0.75, 1] \times \text{Observation Area } [0, 0.5, 1] \times \text{Positive Control } [0, 0.5, 1] \quad (5\text{-}4)$$

5.2.1 Sonar and Other Transducers

To quantify the number of marine mammals and sea turtles predicted to be sighted by Lookouts during implementation of mitigation in the range to injury (PTS) for sonar and other transducers, the species sight ability is multiplied by the mitigation effectiveness scores and number of model-estimated PTS impacts, as shown in equation (5-5).

Number of animals sighted by Lookouts = Mitigation Effectiveness x *Model-Estimated Impacts* (5-5)

The marine mammals and sea turtles sighted by Lookouts during implementation of mitigation in the range to PTS, as calculated by equation (5-5), would avoid being exposed to these higher level impacts. The Navy corrects the category of predicted impact for the number of animals sighted within the mitigation zone (e.g., shifts PTS-to-TTS), but does not modify the total number of animals predicted to experience impacts from the scenario.

5.2.2 Explosives

To quantify the number of marine mammals and sea turtles predicted to be sighted by Lookouts during implementation of mitigation in the range to mortality during events using explosives, the species sight

ability is multiplied by the mitigation effectiveness scores and number of model-estimated mortality impacts, as shown in equation (5-4).

The marine mammals and sea turtles predicted to be sighted by Lookouts during implementation of mitigation in the range to mortality, as calculated by equation (5-5), are predicted to avoid exposure in these ranges. The Navy corrects the category of predicted impact for the number of animals sighted within the mitigation zone, but does not modify the total number of animals predicted to experience impacts from the scenario. For example, the number of animals sighted (i.e., number of animals that will avoid mortality) is first subtracted from the model-predicted mortality impacts, and then added to the model-predicted injurious impacts.

5.2.3 Factors not Considered Quantitatively

It is important to note that there are additional protections offered by mitigation measures that will further reduce marine mammal and sea turtle exposures to sound-producing activities, but are not considered quantitatively in the analysis. Consistent with the Navy's impact assessment processes, mitigation effectiveness was incorporated conservatively (i.e., erring on the side of underestimating effectiveness) when quantitatively adjusting model-estimated effects to marine species within the applicable mitigation zones. Conservative considerations include the following:

- The Navy did not quantitatively account for mitigation during scenarios that were given a mitigation effectiveness factor of zero. A mitigation effectiveness factor of zero was given to scenarios where less than half of the mitigation zone can be continuously visually observed. However, some protection from applied mitigation measures would be afforded during these activities.
- The Navy only accounted for mitigation based on the required number of Lookouts, but did not account for detections that could be made by other personnel that may be involved with a scenario (such as range support personnel aboard a torpedo retrieval boat or support aircraft) or detections that could be made by watch personnel under implementation of Standard Operating Procedures, even though information about marine mammal sightings are shared among units participating in the training or testing activity.
- The Navy did not quantify the potential for mitigation to reduce model-estimated TTS or behavioral impacts, although implementation of mitigation would likely prevent some TTS in many species and reduce the number and severity of some behavioral reactions.
- Mitigation involving a power-down of sonar, cessation of sonar, or delay in use of explosives as a result of a marine mammal or sea turtle detection protects the observed animal and all unobserved (below the surface) animals in the vicinity. The consideration of implementation of mitigation in the post-model analysis, however, conservatively assumes that only observed animals, approximated by considering the species-specific g(0) and event-specific mitigation effectiveness factor, would be protected by the applied mitigation (i.e., a power down, cessation of sonar, or event delay). The quantitative post-model mitigation analysis, therefore, does not capture the protection afforded to all unobserved marine species that may be near or within the mitigation zone.

6. Avoidance by Animals of High Sound Levels from Sonar and Other Transducers

The NAEMO overestimates the number of marine mammals and sea turtles that would be exposed to sound sources that could cause PTS because the model does not consider horizontal movement of animats including avoidance of high intensity sound exposures. Therefore, the potential for animal avoidance is considered separately. At close ranges and high sound levels, avoidance of the area immediately around the sound source is one of the assumed behavioral responses for marine mammals. Animal avoidance refers to the movement out of the immediate injury zone for subsequent exposures, not wide-scale area avoidance. Various researchers have demonstrated that cetaceans can perceive the location and movement of a sound source (e.g., vessel, seismic source, etc.) relative to their own location and react with responsive movement away from the source, often at distances of a kilometer or more (Au & Perryman, 1982; Jansen et al., 2010; Richardson et al., 1995; Tyack et al., 2011; Watkins, 1986; Würsig et al., 1998). A marine mammal's ability to avoid a sound source and reduce its cumulative sound energy exposure would reduce risk of both PTS and TTS. However, the quantitative analysis conservatively only considers the potential to reduce some instances of PTS by accounting for marine mammals swimming away to avoid repeated high-level sound exposures. All reductions in PTS impacts from likely avoidance behaviors are instead considered TTS impacts.

While in general, the louder the sound source the more intense the behavioral response, the proximity of a sound source and the animal's experience, motivation, and conditioning were also critical factors influencing the response outlined an approach to assessing the effects of sound on marine mammals that incorporates these contextual-based factors. They recommend considering not just the received level of sound, but also in what activity the animal is engaged, the nature and novelty of the sound (i.e., is this a new sound from the animal's perspective), and the distance between the sound source and the animal. They submit that this "exposure context," as described, greatly influences the type of behavioral response exhibited by the animal (see technical report *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects to Marine Mammals and Sea Turtles (U.S. Department of the Navy, 2017c)*).

An extensive review of literature on marine mammal behavioral responses to sonar and other transducers occurred for the development of behavioral response functions in the Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects to Marine Mammals and Sea Turtles (U.S. Department of the Navy, 2017c). Due to the breadth of marine mammal behavioral response literature, individual studies will not be discussed in detail in this technical report. However, general conclusions can be drawn from the literature, such as the received sound level to which species will behaviorally respond:

- Odontocetes (mid- and high-frequency cetacean species groups): Responses occurred between 94 and 185 dB re 1 µPa with a mean response range between 126 and 169 dB re 1 µPa.
- Pinnipeds (phocid and otariid species groups): In water responses occurred between 125 and 185 dB re 1 µPa with a mean response range between 159 and 170 dB re 1 µPa.
- Mysticetes (low-frequency cetacean species group): Responses occurred between 107 and 165 dB re 1 µPa with a mean response range between 123 and 139 dB re 1 µPa.
- Beaked whales (mid-frequency cetacean species group): Responses occurred between 95 and 142 dB re 1 µPa.
- Harbor porpoise (high-frequency cetacean species group): A step function at an SPL of 120 dB re 1 µPa is used for harbor porpoises as a threshold to predict potential significant behavioral responses.

- Sirenians (low-frequency cetacean species group [surrogate]): Due to a lack of behavioral response data for sirenians, behavioral response data from mysticetes are used as a proxy due to similarities in behavioral traits and distant taxonomic relation.

Per discussions with NMFS, the received sound level at which sea turtles are expected to actively avoid air gun exposures, *175 dB re 1 µPa SPL rms* based on studies of sea turtles exposed to air guns (McCauley et al., 2000), is also expected to be the received sound level at which sea turtles would actively avoid exposure to sonar and other transducers during Navy training and testing activities. This behavioral threshold will be applied to sources up to 2 kHz.

For Phase III analyses, with the exception of the high-frequency cetacean species group, all other species groups including sea turtles have an in water weighted PTS threshold greater than or equal to 198 dB re 1 μPa^2 s for non-impulsive sources (U.S. Department of the Navy, 2017c). In addition, the majority of species groups have a weighted TTS threshold greater than 178 dB re 1 μPa^2s for non-impulsive sources. The high-frequency cetacean species group has lower TTS and PTS thresholds; however the hearing group is comprised of some species that have exhibited a high level of sensitivity to human activity. For example, dwarf and pygmy sperm whales are not often observed at sea, but they are among the more frequently stranded cetaceans (Caldwell & Caldwell, 1989; Jefferson et al., 2008; McAlpine, 2009). Rare sightings indicate they may avoid human activity, and they are rarely active at the sea surface.

Generally, the sound levels necessary for animals to experience PTS are much higher than the behavioral response thresholds reported in the literature. Therefore, it is expected that animals would avoid repeated exposures and reduce cumulative sound energy exposure necessary to induce PTS. During the first few pings of a training or testing event, or after a pause in sonar activities, if animals are caught unaware and it was not possible to implement mitigation measures (e.g., animals are at depth and not visible at the surface) it is possible they could receive enough acoustic energy to suffer PTS. Based on nominal marine mammal and sea turtle swim speeds (i.e., 3 knots) and normal operating parameters for Navy vessels (i.e., 10–15 knots), it was determined that an animal can easily avoid PTS zones within the timeframe it takes an active sound source to generate one to two pings from a moving vessel-based source.

Animals present beyond the range to onset PTS for the first three to four pings are assumed to avoid any additional exposures at levels that could cause PTS. This equates to approximately 5 percent of the total pings or 5 percent of the overall time active; therefore, 95 percent of marine mammals predicted to experience PTS due to sonar and other transducers are instead assumed to experience TTS. Although some of the predicted impacts are re-categorized, the overall number of animals predicted to be affected is unchanged.

7. RANGE TO EFFECTS

7.1 NAEMO Impulsive Modeling Comparison with Experimental Data

The NAEMO Phase III explosive modeling process has been compared to experimental data collected in the Virginia Capes (VACAPES) Range Complex and at the Silver Strand Training Complex areas. Additional experimental data have recently been collected at the Pu'uloa range site but has not been compared to NAEMO data. However, in all of the available experimental datasets, the explosive charge sizes (less than 24 lb net explosive weight) used for these experiments are at the lower end of the spectrum of charge sizes being modeled in Phase III. Furthermore, the water depths and measurement distances (less than 10 m of water depth and a maximum of 1,700 m from the source) are relatively small compared to the Phase III predicted range to effects distances of interest. Nonetheless, the comparisons made between the experimental data and NAEMO model data showed good correlation of peak pressures indicating that the NAMEO impulsive modeling process is in agreement with experimental data for the limited datasets used for the comparisons. To fully conduct a validation of the NAEMO impulsive modeling process would require additional datasets for several of the larger charge sizes in multiple environmental conditions and at distances similar to the predicted range to effects distances.

7.2 Limitations with Using Similitude Equation

A theoretical representation of the impulsive source signatures defined by the similitude equation is used in NAEMO as input into the explosive modeling process. This approach was selected due the limited datasets available for the wide range of explosive charge sizes being modeled in Phase III. As with any theoretical representation, there are limitations and assumptions that need to be considered. One of the limitations identified by Swisdak (1978) is the range in pressure over which the similitude equation is valid. For explosives represented in net explosive weight of TNT, the valid range reported is from 3.4-to-138 MPa. Converting this into charge size produces a net explosive weight of TNT of 28.8 lb, which is equivalent to Phase III impulsive bin E5. Charge sizes above this weight would then fall outside of the pressure range for which this equation is valid. Unfortunately, the reference for the pressure range is from unpublished data which makes it impossible to review. To provide confidence in the use of the similitude equation, both within the pressure range and above the stated maximum validity range, a series of analysis runs were conducted using the NAEMO modeling process. For each analysis the peak pressure was computed at various radial distances from the source location and compared to the theoretical value based on similitude. The comparison showed good agreement between the NAMEO model and the similitude equation peak pressures at each of the distances reviewed. Based on this evaluation, the use of the similitude equation to represent impulsive source signatures was determined to be acceptable for the purposes of the NAEMO simulations.

The similitude equation is based on a closed form approximation of the explosive shockwave that is produced during underwater detonations. The basic form of the equation only produces positive pressures which violates conservation of mass/energy laws. Further research done by the originator of the method has yielded a closed form approximation that can match both peak overpressure and also give under-pressure to restore balance to the system. The new modified similitude equation developed by Friedlander (1946) was subsequently used for the NAEMO model.

The effect on propagation due to changing from similitude to a Friedlander source signature was examined at two locations (shallow and deep) for a near surface 1,000 lb net explosive weight charge. Generally there is excellent agreement for both locations with respect to peak SPL and unweighted SEL. The vast majority of peak SPL is within 3 dB and SEL is within 2 dB. A harbor porpoise calf (5 lb) was used to compare impulse. Comparisons in $\log_{10}(\mathrm{I})$ space show at most a factor of 101.5 (≈ 32) increase in

the impulse. However, these differences are usually beyond the range at which 1% slight lung injury occurs. Within the range of effects of concern the change to the impulse is minimal.

7.3 Surface Effects for Near Surface Detonations

The impulsive modeling approach used in NAEMO cannot account for the highly non-linear effects of cavitation and surface blowoff that would exist in the real world. To approximate these effects a series of analyses were conducted with the charge depths defined at varying distances from the free surface. The results of these simulations were compared to modeling using the Reflection and REFMS. Based on these comparisons a depth of 0.1 m was chosen as the representative depth for near surface detonations.

7.4 Ray Trace Model Limitations

The NAEMO impulsive modeling process utilizes the Navy's CASS/GRAB model as developed by Weinberg and Keenan (1996). CASS/GRAB is the Navy's standard ray trace model for computing the propagation of sound in an underwater environment. As with any computational model there are inherent limitations on how and where the model should be used. One of these limitations is the frequency of the source being modeled compared to the overall water depths at the location of interest. In general, the wavelength of the source should be small compared to the water depth, bathymetric features, and any internal features such as ducts (Janson et al., 2010). The approach used in NAEMO to model broadband impulsive sources is to break up the signature into 1/3 octave bins and model each bin separately and then combine the outputs from each bin to produce the overall effects of the impulsive source. In creating these bins some of them will be centered at low-frequencies which can have relatively large wavelengths compared to some of the environments being modeled for underwater detonations. Under some conditions the wave lengths may be too large in comparison to the water depth. However, due to the small number of potential locations where this may occur and the initial comparisons made to the shallow water data, it was determined that there would be minimal impacts to the estimated effects and take numbers produced by NAEMO's modeling process.

8. GUILD AND STOCK BREAKOUTS

Marine mammals and sea turtles in the Navy Marine Species Density Database, and therefore, the NAEMO results, are grouped by species in most cases. In some cases species can be difficult to distinguish from one-another during surveys at sea and are only reported as a group of similar species, or "guilds". The proportion of each species within each guild is estimated based on sightings where species can be determined. Based on these proportions, predicted impacts to guilds are separated out to the species level. Similarly, many species within the study area are divided into multiple stocks for management purposes. Depending on the area, predicted impacts are assigned to the stock that is present, or in the case of areas with overlapping stock, the predicted impacts are broken out by the estimated proportion of each stock that is present. In order to keep results consistent across regions, these guild-to-species and species-to-stock impact breakouts are assessed after the modeling is completed, such that the final results are always presented at both the species level and the stock level, if applicable. For example, in Atlantic Fleet Training and Testing (AFTT), dwarf and pygmy sperm whale species, which combined make up the Kogia guild, have separate density estimates that are used in NAEMO, and also have Atlantic and Gulf of Mexico stocks that are broken out post-modeling. In contrast, in HSTT only the Kogia guild has a density estimate in the Southern California portion of the HSTT Study Area and is modeled as such in NAEMO, but in the Hawaiian region there are separate densities for dwarf and pygmy sperm whales and no further subdivisions for stock. As another example, bottlenose dolphins in HSTT are modeled in NAEMO at the level of the stock; after modeling these results are presented as stocks but are also combined for a single species-level value. In AFTT, bottlenose dolphins are modeled as a species and then the impacts are broken out by stock post-modeling; in this case, there are several stocks in the Gulf of Mexico and Atlantic Ocean that never overlap with Navy activity, and therefore, are excluded from this post-model breakout analysis. Finally, Bryde's whales in HSTT are modeled in NAEMO as a single species but are broken out into two stocks after modeling. In AFTT there is only one designated stock of Bryde's whales (the Gulf of Mexico stock); however, the species occur in both the Gulf of Mexico and the Atlantic Ocean. Therefore, although impacts are assessed for the species as a whole, and although the stock in the Gulf of Mexico is very small (33 animals), all impacts are assigned to the single stock even though animals in the Atlantic were modeled to overlap with Navy activity as well.

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9. RANGE TO EFFECTS TABLES

9.1 AFTT Marine Mammals and Reptiles

9.1.1 Impact Ranges for Sonar and Other Transducers

The ranges to the PTS threshold for an exposure of 30 seconds are shown in tables 9-1 and 9-7 relative to a functional hearing group. This period (30 seconds) was chosen based on examining the maximum amount of time a marine mammal would realistically be exposed to levels that could cause the onset of PTS based on platform (e.g., ship) speed and a nominal animal swim speed of approximately 1.5 meters per second. The ranges provided in the table include the average range to PTS, as well as the range from the minimum to the maximum distance at which PTS is possible for each hearing group.

Since any hull-mounted sonar, such as the SQS-53, engaged in antisubmarine warfare training would be moving at between 10–15 knots and nominally pinging every 50 seconds, the vessel will have traveled a minimum distance of approximately 257 m during the time between those pings (note: 10 knots is the speed used in the Navy Acoustic Effects Model). As a result, there is little overlap of PTS footprints from successive pings, indicating that in most cases, an animal predicted to receive PTS would do so from a single exposure (i.e., ping). For all other bins (besides MF1), PTS ranges are short enough that marine mammals (with a nominal swim speed of approximately 1.5 meters per second) should be able to avoid higher sound levels capable of causing onset PTS within this 30-second period.

For all other functional hearing groups (low-frequency cetaceans, mid-frequency cetaceans, and phocid seals and sirenia), 30-second average PTS zones are substantially shorter. A scenario could occur where an animal does not leave the vicinity of a ship or travels a course parallel to the ship; however, the close distances required make PTS exposure unlikely. For a Navy vessel moving at a nominal 10 knots, it is unlikely a marine mammal could maintain the speed to parallel the ship and receive adequate energy over successive pings to suffer PTS.

The tables below illustrate the range to TTS for 1, 30, 60, and 120 seconds from five representative sonar systems (Tables 9-2 through 9-6 and Tables 9-8 through 9-14). Due to the lower acoustic thresholds for TTS versus PTS, ranges to TTS are longer. Therefore, successive pings can be expected to add together, further increasing the range to onset-TTS.

Table 9-1. AFTT Acoustic Ranges to PTS for Marine Mammals

Hearing Group	***Approximate PTS (30 seconds) Ranges (meters)[1]***				
	Sonar bin LF5M	***Sonar bin MF1***	***Sonar bin MF4***	***Sonar bin MF5***	***Sonar bin HF4***
HF Cetacean	0 (0—0)	192 (170—270)	31 (30—40)	9 (8—13)	34 (20—85)
LF Cetacean	0 (0—0)	66 (65—80)	15 (15—18)	0 (0—0)	0 (0—0)
MF Cetacean	0 (0—0)	16 (16—16)	3 (3—3)	0 (0—0)	1 (0—2)
Phocinae	0 (0—0)	46 (45—55)	11 (11—13)	0 (0—0)	0 (0—0)

Table 9-1. AFTT Acoustic Ranges to PTS for Marine Mammals (Cont'd)

Hearing Group	Approximate PTS (30 seconds) Ranges (meters)[1]				
	Sonar bin LF5M	Sonar bin MF1	Sonar bin MF4	Sonar bin MF5	Sonar bin HF4
Sirenia	0 (0—0)	16 (16—16)	0 (0—0)	0 (0—0)	0 (0—0)

[1] PTS ranges extend from the sonar or other active acoustic sound source to the indicated distance. The average range to PTS is provided as well as the range from the estimated minimum to the maximum range to PTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to PTS are the same.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-2. AFTT Sonar Bin LF5M Ranges to TTS for Marine Mammals

Hearing Group	Approximate TTS Ranges (meters)[1]			
	Sonar Bin LF5M			
	1 second	30 seconds	60 seconds	120 seconds
HF Cetacean	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
LF Cetacean	4 (0—5)	4 (0—5)	4 (0—5)	4 (0—5)
MF Cetacean	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
Phocinae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
Sirenia	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-3. AFTT Sonar Bin HF4 Ranges to TTS for Marine Mammals

Hearing Group	Approximate TTS Ranges (meters)[1]			
	Sonar Bin HF4			
	1 second	30 seconds	60 seconds	120 seconds
HF Cetacean	242 (100—975)	395 (170—1775)	524 (230—2775)	655 (300—4275)
LF Cetacean	1 (0—3)	3 (0—5)	5 (0—7)	7 (0—12)
MF Cetacean	10 (7—17)	19 (11—35)	27 (17—60)	39 (22—100)

Table 9-3. AFTT Sonar Bin HF4 Ranges to TTS for Marine Mammals (Cont'd)

Hearing Group	Approximate TTS Ranges (meters)[1]			
	Sonar Bin HF4			
	1 second	30 seconds	60 seconds	120 seconds
Phocinae	2 (0—5)	5 (0—8)	8 (5—13)	12 (8—20)
Sirenia	0 (0—2)	1 (0—3)	1 (0—5)	2 (0—8)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-4. AFTT Sonar Bin MF1 Ranges to TTS for Marine Mammals

Hearing Group	Approximate TTS Ranges (meters)[1]			
	Sonar Bin MF1			
	1 second	30 seconds	60 seconds	120 seconds
HF Cetacean	3001 (1275—8275)	3001 (1275—8275)	4803 (1525—13525)	6016 (1525—16775)
LF Cetacean	1111 (650—2775)	1111 (650—2775)	1655 (800—3775)	2160 (900—6525)
MF Cetacean	222 (200—310)	222 (200—310)	331 (280—525)	424 (340—800)
Phocinae	784 (575—1275)	784 (575—1275)	1211 (850—3025)	1505 (1025—3775)
Sirenia	223 (200—310)	223 (200—310)	331 (270—525)	423 (330—800)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-5. AFTT Sonar Bin MF4 Ranges to TTS for Marine Mammals

Hearing Group	*Approximate TTS Ranges (meters)*[1]			
	Sonar Bin MF4			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
HF Cetacean	270 (220—575)	546 (410—1025)	729 (525—1525)	1107 (600—2275)
LF Cetacean	89 (85—120)	175 (160—280)	262 (220—575)	429 (330—875)
MF Cetacean	22 (22—25)	36 (35—45)	51 (45—60)	72 (70—95)
Phocinae	67 (65—90)	119 (110—180)	171 (150—260)	296 (240—700)
Sirenia	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-6. AFTT Sonar Bin MF5 Ranges to TTS for Marine Mammals

Hearing Group	*Approximate TTS Ranges (meters)*[1]			
	Sonar Bin MF5			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
HF Cetacean	122 (110—320)	122 (110—320)	187 (150—525)	286 (210—750)
LF Cetacean	11 (0—14)	11 (0—14)	16 (0—20)	23 (0—25)
MF Cetacean	5 (0—10)	5 (0—10)	12 (0—15)	17 (0—22)
Phocinae	9 (8—13)	9 (8—13)	15 (14—18)	22 (21—25)
Sirenia	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-7. AFTT Acoustic Ranges to PTS for Sea Turtles

Hearing Group	*Approximate PTS (30 seconds) Ranges (meters)[1]*				
	Sonar bin LF5M	*Sonar bin MF1*	*Sonar bin MF4*	*Sonar bin MF5*	*Sonar bin HF4*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] PTS ranges extend from the sonar or other active acoustic sound source to the indicated distance. The average range to PTS is provided as well as the range from the estimated minimum to the maximum range to PTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to PTS are the same.
Notes: ASW: anti-submarine warfare; HF: high frequency; LF: low frequency; MF: mid-frequency; MIW: mine warfare PTS: permanent threshold shift

Table 9-8. AFTT Sonar Bin LF5M Ranges to TTS for Sea Turtles

Hearing Group	*Approximate TTS Ranges (meters)[1]*			
	Sonar Bin LF5M			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-9. AFTT Sonar Bin HF4 Ranges to TTS for Sea Turtles

Hearing Group	*Approximate TTS Ranges (meters)[1]*			
	Sonar Bin HF4			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-10. AFTT Sonar Bin MF1 Ranges to TTS for Sea Turtles

Hearing Group	***Approximate TTS Ranges (meters)[1]***			
	Sonar Bin MF1			
	1 second	***30 seconds***	***60 seconds***	***120 seconds***
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-11. AFTT Sonar Bin MF4 Ranges to TTS for Sea Turtles

Hearing Group	***Approximate TTS Ranges (meters)[1]***			
	Sonar Bin MF4			
	1 second	***30 seconds***	***60 seconds***	***120 seconds***
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-12. AFTT Sonar Bin MF5 Ranges to TTS for Sea Turtles

Hearing Group	***Approximate TTS Ranges (meters)[1]***			
	Sonar Bin MF5			
	1 second	***30 seconds***	***60 seconds***	***120 seconds***
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parenthesis. Where only one number is provided the average, minimum, and maximum, ranges to TTS are the same.
Notes: ASW: anti-submarine warfare; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

9.1.2 Impact Ranges for Explosives

The following section provides the range (distance) over which specific physiological or behavioral effects are expected to occur based on the explosive criteria (U.S. Department of the Navy, 2017c) and the explosive propagation calculations from the Navy Acoustic Effects Model (U.S. Department of the Navy, 2017d). The range to effects are shown for a range of explosive bins, from E1 (up to 0.25 lb. net explosive weight) to E17 (up to 58,000 lb. net explosive weight). Ranges are determined by modeling the distance that noise from an explosion will need to propagate to reach exposure level thresholds specific

to a hearing group that will cause behavioral response, TTS, PTS, and non-auditory injury. Range to effects is important information in not only predicting impacts from explosives, but also in verifying the accuracy of model results against real-world situations and determining adequate mitigation ranges to avoid higher level effects, especially physiological effects to marine mammals.

Tables 9-13 and 9-25 show the minimum, average, and maximum ranges due to varying propagation conditions to non-auditory injury as a function of animal mass and explosive bin (i.e., net explosive weight). These ranges represent the larger of the range to slight lung injury or gastrointestinal tract injury for different representative animal masses ranging from 10-to-72,000 kg and different explosive bins ranging from 0.25-to-58,000 lb net explosive weight. Animals within these water volumes would be expected to receive minor injuries at the outer ranges, increasing to more substantial injuries, and finally mortality (Tables 9-14 and 9-26) as an animal approaches the detonation point.

The following Tables 9-15 through 9-24 and Tables 9-27 and 9-28 show the minimum, average, and maximum ranges to onset of auditory and behavioral effects based on the thresholds described in The Criteria and Thresholds for Assessing Acoustic and Explosive Impacts to Marine Mammals and Sea Turtles technical report (U.S. Department of the Navy, 2017c). Ranges are provided for a representative source depth and cluster size for each bin. For events with multiple explosions, sound from successive explosions can be expected to accumulate and increase the range to the onset of an impact based on SEL thresholds. Modeled ranges to TTS and PTS based on peak pressure for a single explosion generally exceed the modeled ranges based on SEL even when accumulated for multiple explosions. Peak pressure based ranges are estimated using the best available science; however, data on peak pressure at far distances from explosions are very limited. For additional information on how ranges to impacts from explosions were estimated, see the technical report Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing Ranges (U.S. Department of the Navy, 2017d). Therefore, ranges based on SEL and peak pressure to behavioral response, TTS, and PTS are presented to depict the different ranges to impacts based on the two sound metrics.

Table 9-13. Ranges[1] to Non-Auditory Injury for All Marine Mammal Hearing Groups as a Function of Animal Mass.

Bin	***Animal Mass Intervals (kg)[1]***					
	10	***250***	***1,000***	***5,000***	***25,000***	***72,000***
E1	22 (22—35)	22 (22—35)	22 (22—35)	22 (22—35)	22 (22—35)	22 (22—35)
E2	25 (25—30)	25 (25—30)	25 (25—30)	25 (25—30)	25 (25—30)	25 (25—30)
E3	46 (35—75)	46 (35—75)	46 (35—75)	46 (35—75)	46 (35—75)	46 (35—75)
E4	63 (0—130)	63 (0—130)	63 (0—130)	63 (0—130)	63 (0—130)	63 (0—130)
E5	75 (55—130)	75 (55—130)	75 (55—130)	75 (55—130)	75 (55—130)	75 (55—130)
E6	97 (65—390)	97 (65—390)	97 (65—390)	97 (65—390)	97 (65—390)	97 (65—390)

Table 9-13. Ranges[1] to Non-Auditory Injury for All Marine Mammal Hearing Groups as a Function of Animal Mass (Cont'd)

Bin	Animal Mass Intervals (kg)[1]					
	10	250	1,000	5,000	25,000	72,000
E7	232 (200—270)	181 (140—210)	181 (140—210)	181 (140—210)	181 (140—210)	181 (140—210)
E8	170 (0—490)	170 (0—490)	170 (0—490)	170 (0—490)	170 (0—490)	170 (4—490)
E9	215 (100—430)	215 (100—320)	215 (100—240)	215 (100—240)	215 (100—240)	215 (100—240)
E10	251 (110—700)	248 (110—550)	248 (110—320)	248 (110—320)	248 (110—320)	248 (110—320)
E11	604 (400—2,525)	402 (260—2,025)	402 (260—1,025)	402 (260—1,025)	402 (260—1,025)	402 (260—1,025)
E12	436 (130—1,025)	336 (130—725)	336 (130—390)	336 (130—390)	336 (130—390)	336 (130—390)
E16	1,844 (925—3,025)	1,844 (725—10,025)	1,844 (625—3,025)	1,844 (625—3,025)	1,844 (625—3,025)	1,844 (625—3,025)
E17	3,649 (1,000—14,025)	2,435 (850—10,525)	2,435 (825—5,525)	2,435 (850—5,525)	2,435 (825—5,525)	2,435 (825—5,525)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-14. Ranges[1] to Mortality for All Marine Mammal Hearing Groups as a Function of Animal Mass.

Bin	Animal Mass Intervals (kg)[1]					
	10	250	1,000	5,000	25,000	72,000
E1	4 (3—5)	1 (0—3)	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
E2	5 (5—7)	3 (0—5)	0 (0—2)	0 (0—0)	0 (0—0)	0 (0—0)
E3	11 (9—15)	6 (3—11)	3 (2—4)	0 (0—2)	0 (0—0)	0 (0—0)
E4	20 (0—45)	11 (0—30)	5 (0—13)	3 (0—6)	1 (0—2)	0 (0—2)
E5	18 (14—50)	10 (5—35)	5 (3—11)	3 (2—6)	0 (0—3)	0 (0—2)
E6	26 (17—75)	14 (0—55)	7 (0—20)	4 (3—10)	2 (0—4)	1 (0—3)
E7	100 (75—130)	49 (25—95)	21 (17—30)	13 (11—15)	7 (6—7)	5 (4—6)
E8	69 (0—140)	36 (0—100)	16 (0—30)	12 (0—17)	6 (0—8)	5 (0—7)
E9	58 (40—200)	26 (17—55)	14 (11—18)	9 (8—11)	5 (4—5)	4 (3—5)

Table 9-14. Ranges[1] to Mortality for All Marine Mammal Hearing Groups as a Function of Animal Mass (Cont'd)

Bin	*Animal Mass Intervals (kg)[1]*					
	10	*250*	*1,000*	*5,000*	*25,000*	*72,000*
E10	107 (40—320)	39 (19—220)	18 (14—35)	12 (10—21)	6 (6—9)	5 (4—6)
E11	299 (230—675)	163 (90—490)	74 (55—150)	45 (35—85)	24 (21—40)	19 (15—30)
E12	194 (60—460)	82 (25—340)	22 (18—30)	15 (12—17)	8 (7—9)	6 (5—7)
E16	1,083 (925—1,525)	782 (500—1,025)	423 (350—550)	275 (230—300)	144 (130—150)	105 (90—120)
E17	1,731 (925—2,525)	1,222 (700—2,275)	857 (575—1,025)	586 (470—825)	318 (290—340)	244 (210—280)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-15. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for High-Frequency Cetaceans

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	446 (180—975)	1,512 (525—3,775)	2,591 (800—6,775)
	0.1	20	1,289 (440—3,025)	4,527 (1,275—10,775)	6,650 (1,525—16,525)
E2	0.1	1	503 (200—1,025)	1,865 (600—3,775)	3,559 (1,025—6,775)
	0.1	2	623 (250—1,275)	2,606 (750—5,275)	4,743 (1,275—8,525)
E3	18.25	1	865 (525—2,525)	3,707 (1,025—6,775)	5,879 (1,775—10,025)
	18.25	50	4,484 (1,275—7,775)	10,610 (2,275—19,775)	13,817 (2,275—27,025)

Table 9-15. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for High-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E4	15	1	1,576 (1,025—2,275)	6,588 (4,525—8,775)	9,744 (7,275—13,025)
	15	5	3,314 (2,275—4,525)	10,312 (7,525—14,775)	14,200 (9,775—20,025)
	19.8	2	1,262 (975—2,025)	4,708 (1,775—7,525)	6,618 (2,025—11,525)
	198	2	1,355 (875—2,775)	4,900 (2,525—8,275)	6,686 (3,025—11,275)
E5	0.1	25	3,342 (925—8,025)	8,880 (1,275—20,525)	11,832 (1,525—25,025)
E6	0.1	1	1,204 (550—3,275)	4,507 (1,275—10,775)	6,755 (1,525—16,525)
	30	1	2,442 (1,525—5,025)	7,631 (4,525—10,775)	10,503 (4,775—15,025)
E7	15	1	3,317 (2,525—4,525)	10,122 (7,775—13,275)	13,872 (9,775—17,775)
E8	0.1	1	1,883 (675—4,525)	6,404 (1,525—14,525)	9,001 (1,525—19,775)
	45.75	1	2,442 (1,025—5,525)	7,079 (2,025—12,275)	9,462 (2,275—17,025)
	305	1	3,008 (2,025—4,025)	9,008 (6,025—10,775)	12,032 (8,525—14,525)
E9	0.1	1	2,210 (800—4,775)	6,088 (1,525—13,275)	8,299 (1,525—19,025)
E10	0.1	1	2,960 (875—7,275)	8,424 (1,525—19,275)	11,380 (1,525—24,275)
E11	18.5	1	4,827 (1,525—8,775)	11,231 (2,525—20,025)	14,667 (2,525—26,775)
	45.75	1	3,893 (1,525—7,525)	9,320 (2,275—17,025)	12,118 (2,525—21,525)
E12	0.1	1	3,046 (1,275—6,775)	7,722 (1,525—18,775)	10,218 (2,025—22,525)

Table 9-15. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for High-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E16	61	1	5,190 (2,275—9,775)	7,851 (3,525—19,525)	9,643 (3,775—25,775)
E17	61	1	6,173 (2,525—12,025)	11,071 (3,775—29,275)	13,574 (4,025—37,775)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-16. Peak Pressure Based Ranges to Onset PTS and Onset TTS for High-Frequency Cetaceans

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E1	0.1	579 (200—975)	883 (300—3,025)
E2	0.1	493 (230—1,275)	879 (360—3,525)
E3	18.25	2,052 (950—5,025)	3,580 (1,025—8,275)
E4	15	3,324 (2,025—5,025)	7,679 (3,775—12,775)
	19.8	2,205 (1,275—4,275)	3,549 (2,275—5,525)
	198	2,841 (1,775—6,275)	4,009 (2,775—7,275)
E5	0.1	1,459 (490—7,775)	2,805 (875—17,775)
E6	0.1	1,956 (800—7,775)	4,071 (1,275—23,025)
	30	4,339 (2,025—10,025)	7,633 (3,025—17,025)
E7	15	9,900 (5,025—18,025)	15,456 (8,775—27,775)

Table 9-16. Peak Pressure Based Ranges to Onset PTS and Onset TTS for High-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E8	0.1	4,312 (1,025—26,775)	7,430 (1,525—53,275)
	45.75	6,941 (1,775—20,275)	11,610 (1,775—36,525)
	305	6,518 (3,275—10,775)	9,129 (4,525—18,025)
E9	0.1	4,129 (1,525—40,275)	6,770 (1,525—71,275)
E10	0.1	7,509 (1,525—53,775)	12,597 (1,775—76,775)
E11	18.5	14,627 (2,275—44,775)	22,673 (4,025—68,275)
	45.75	13,105 (2,025—41,775)	22,150 (2,775—65,775)
E12	0.1	6,551 (1,525—71,275)	11,162 (2,275—85,275)
E16	61	29,544 (17,525—59,275)	39,829 (24,525—92,775)
E17	61	39,317 (18,775—99,275)	52,954 (23,025—98,775)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-17. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Low-Frequency Cetaceans

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	54 (45—80)	259 (130—390)	137 (90—210)
	0.1	20	211 (110—320)	787 (340—1,525)	487 (210—775)
E2	0.1	1	64 (55—75)	264 (150—400)	154 (100—220)
	0.1	2	87 (70—110)	339 (190—500)	203 (120—300)

Table 9-17. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Low-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E3	18.25	1	211 (190—390)	1,182 (600—2,525)	588 (410—1,275)
	18.25	50	1,450 (675—3,275)	8,920 (1,525—24,275)	4,671 (1,025—10,775)
E4	15	1	424 (380—550)	3,308 (2,275—4,775)	1,426 (1,025—2,275)
	15	5	1,091 (950—1,525)	6,261 (3,775—9,525)	3,661 (2,525—5,275)
	19.8	2	375 (350—400)	1,770 (1,275—3,025)	1,003 (725—1,275)
	198	2	308 (280—380)	2,275 (1,275—3,525)	1,092 (850—2,275)
E5	0.1	25	701 (300—1,525)	4,827 (750—29,275)	1,962 (575—22,525)
E6	0.1	1	280 (150—450)	1,018 (460—7,275)	601 (300—1,525)
	30	1	824 (525—1,275)	4,431 (2,025—7,775)	2,334 (1,275—4,275)
E7	15	1	1,928 (1,775—2,275)	8,803 (6,025—14,275)	4,942 (3,525—6,525)
E8	0.1	1	486 (220—1,000)	3,059 (575—20,525)	1,087 (440—7,775)
	45.75	1	1,233 (675—3,025)	7,447 (1,275—19,025)	3,633 (1,000—9,025)
	305	1	937 (875—975)	6,540 (3,025—12,025)	3,888 (2,025—6,525)
E9	0.1	1	655 (310—1,275)	2,900 (650—31,025)	1,364 (500—8,525)
E10	0.1	1	786 (340—7,275)	7,546 (725—49,025)	3,289 (550—26,525)
E11	18.5	1	3,705 (925—8,775)	16,488 (2,275—40,275)	9,489 (1,775—22,775)
	45.75	1	3,133 (925—8,275)	16,365 (1,775—50,275)	8,701 (1,275—23,775)

Table 9-17. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Low-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E12	0.1	1	985 (400—6,025)	7,096 (800—72,775)	2,658 (625—46,525)
E16	61	1	10,155 (2,025—21,525)	35,790 (18,025—69,775)	25,946 (14,025—58,775)
E17	61	1	17,464 (8,275—39,525)	47,402 (21,025—93,275)	34,095 (16,275—86,275)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-18. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Low-Frequency Cetaceans

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]			
Bin	Source Depth (m)	PTS	TTS
E1	0.1	127 (75—170)	226 (100—270)
E2	0.1	120 (85—150)	189 (110—270)
E3	18.25	336 (260—1,275)	674 (420—2,275)
E4	15	522 (410—875)	1,159 (775—2,025)
	19.8	431 (390—575)	892 (700—1,275)
	198	401 (360—490)	840 (650—1,775)
E5	0.1	387 (150—500)	622 (210—1,275)
E6	0.1	459 (230—625)	724 (370—1,525)
	30	871 (550—1,775)	1,519 (925—2,525)

Table 9-18. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Low-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E7	15	1,914 (1,525—2,275)	3,643 (3,025—4,525)
E8	0.1	703 (360—1,525)	1,062 (525—5,275)
	45.75	1,438 (675—3,525)	2,443 (975—7,025)
	305	1,153 (975—2,025)	3,210 (1,525—5,025)
E9	0.1	926 (480—3,775)	1,409 (600—5,025)
E10	0.1	997 (500—5,275)	1,993 (650—11,025)
E11	18.5	2,855 (950—7,525)	5,356 (1,025—15,525)
	45.75	2,642 (975—7,525)	4,485 (1,025—14,025)
E12	0.1	1,294 (575—4,775)	2,216 (750—17,275)
E16	61	5,118 (1,275—15,275)	12,416 (4,025—25,275)
E17	61	11,226 (3,525—22,775)	18,059 (8,275—37,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-19. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Mid-Frequency Cetaceans

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	26 (25—50)	139 (95—370)	218 (120—550)
	0.1	20	113 (80—290)	539 (210—1,025)	754 (270—1,525)
E2	0.1	1	35 (30—45)	184 (100—300)	276 (130—490)
	0.1	2	51 (40—70)	251 (120—430)	365 (160—700)
E3	18.25	1	40 (35—45)	236 (190—800)	388 (280—1,275)
	18.25	50	304 (230—1,025)	1,615 (750—3,275)	2,424 (925—5,025)
E4	15	1	74 (60—100)	522 (440—750)	813 (650—1,025)
	15	5	192 (140—260)	1,055 (875—1,525)	1,631 (1,275—2,525)
	19.8	2	69 (65—70)	380 (330—470)	665 (550—750)
	198	2	48 (0—55)	307 (260—380)	504 (430—700)
E5	0.1	25	391 (170—850)	1,292 (470—3,275)	1,820 (575—5,025)
E6	0.1	1	116 (90—290)	536 (310—1,025)	742 (380—1,525)
	30	1	110 (85—310)	862 (600—2,275)	1,281 (975—3,275)
E7	15	1	201 (190—220)	1,067 (1,025—1,275)	1,601 (1,275—2,025)
E8	0.1	1	204 (150—500)	802 (400—1,525)	1,064 (470—2,275)
	45.75	1	133 (120—200)	828 (525—2,025)	1,273 (775—2,775)
	305	1	58 (0—110)	656 (550—750)	1,019 (900—1,025)

Table 9-19. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Mid-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E9	0.1	1	241 (200—370)	946 (450—1,525)	1,279 (500—2,275)
E10	0.1	1	339 (230—750)	1,125 (490—2,525)	1,558 (550—4,775)
E11	18.5	1	361 (230—750)	1,744 (800—3,775)	2,597 (925—5,025)
	45.75	1	289 (230—825)	1,544 (800—3,275)	2,298 (925—5,025)
E12	0.1	1	382 (270—550)	1,312 (525—2,775)	1,767 (600—4,275)
E16	61	1	885 (650—1,775)	3,056 (1,275—5,025)	3,689 (1,525—6,525)
E17	61	1	1,398 (925—2,275)	3,738 (1,525—6,775)	4,835 (1,775—9,275)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-20. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Mid-Frequency Cetaceans

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E1	0.1	44 (35—75)	80 (60—110)
E2	0.1	52 (45—70)	82 (70—95)
E3	18.25	101 (95—220)	188 (170—600)

Table 9-20. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Mid-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E4	15	139 (120—230)	278 (230—500)
	19.8	123 (120—130)	243 (230—300)
	198	113 (0—160)	229 (180—270)
E5	0.1	142 (85—170)	252 (110—320)
E6	0.1	175 (100—220)	306 (160—390)
	30	268 (190—575)	514 (370—1,275)
E7	15	415 (330—470)	924 (650—1,025)
E8	0.1	290 (140—350)	476 (230—925)
	45.75	433 (340—1,525)	890 (575—2,275)
	305	333 (250—420)	649 (575—800)
E9	0.1	418 (260—500)	676 (380—1,025)
E10	0.1	457 (220—775)	732 (370—2,025)
E11	18.5	904 (525—2,275)	1,686 (750—4,275)
	45.75	978 (600—2,525)	1,713 (675—5,525)
E12	0.1	608 (340—975)	940 (460—3,775)
E16	61	3,143 (1,000—7,525)	4,580 (1,025—11,025)
E17	61	4,035 (1,025—11,025)	6,005 (1,275—15,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-21. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Phocids

Range to Effects for Explosives Bin: Phocids[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	50 (45—85)	242 (120—470)	360 (160—650)
	0.1	20	197 (110—380)	792 (300—1,275)	1,066 (410—2,275)
E2	0.1	1	65 (55—85)	267 (140—430)	378 (190—675)
	0.1	2	85 (65—100)	345 (180—575)	476 (230—875)
E3	18.25	1	121 (110—220)	689 (500—1,525)	1,074 (725—2,525)
	18.25	50	859 (600—2,025)	4,880 (1,525—10,525)	7,064 (1,775—16,275)
E4	15	1	213 (190—260)	1,246 (1,025—1,775)	2,006 (1,525—3,025)
	15	5	505 (450—600)	2,933 (2,275—4,275)	4,529 (3,275—6,775)
	19.8	2	214 (210—220)	1,083 (900—2,025)	1,559 (1,025—2,525)
	198	2	156 (150—180)	1,141 (825—2,275)	2,076 (1,275—3,525)
E5	0.1	25	615 (250—1,025)	2,209 (850—9,775)	3,488 (1,025—15,275)
E6	0.1	1	210 (160—380)	796 (480—1,275)	1,040 (600—3,275)
	30	1	359 (280—625)	1,821 (1,275—2,775)	2,786 (1,775—4,275)
E7	15	1	557 (525—650)	3,435 (2,775—4,525)	5,095 (3,775—6,775)
E8	0.1	1	346 (230—600)	1,136 (625—4,025)	1,708 (850—6,025)
	45.75	1	469 (380—1,025)	2,555 (1,275—6,025)	3,804 (1,525—9,775)
	305	1	322 (310—330)	3,222 (1,775—4,525)	4,186 (2,275—5,775)
E9	0.1	1	441 (330—575)	1,466 (825—5,775)	2,142 (950—9,775)

Table 9-21. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Phocids (Cont'd)

Range to Effects for Explosives Bin: Phocids[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E10	0.1	1	539 (350—900)	1,914 (875—8,525)	3,137 (1,025—15,025)
E11	18.5	1	1,026 (700—2,025)	5,796 (1,525—12,775)	8,525 (1,775—19,775)
	45.75	1	993 (675—2,275)	4,835 (1,525—13,525)	7,337 (1,775—18,775)
E12	0.1	1	651 (420—900)	2,249 (950—11,025)	3,349 (1,275—16,025)
E16	61	1	2,935 (1,775—5,025)	6,451 (2,275—16,275)	10,619 (3,275—24,025)
E17	61	1	3,583 (1,775—7,525)	12,031 (3,275—29,275)	18,396 (7,275—41,025)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-22. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Phocids

Range to Effects for Explosives Bin: Phocids[1]			
Bin	Source Depth (m)	PTS	TTS
E1	0.1	141 (80—200)	250 (100—310)
E2	0.1	129 (90—170)	204 (120—300)
E3	18.25	377 (290—1,275)	762 (575—2,025)
E4	15	591 (450—1,000)	1,280 (850—2,025)
	19.8	499 (460—625)	1,046 (775—2,025)
	198	458 (430—650)	1,011 (775—2,025)
E5	0.1	430 (150—725)	695 (220—1,275)

Table 9-22. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Phocids (Cont'd)

Range to Effects for Explosives Bin: Phocids[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E6	0.1	509 (250—775)	791 (410—2,025)
	30	996 (575—2,025)	1,677 (975—2,775)
E7	15	2,109 (1,775—3,025)	3,803 (3,025—4,525)
E8	0.1	775 (390—2,025)	1,211 (575—5,275)
	45.75	1,630 (1,025—4,275)	2,814 (1,275—7,025)
	305	1,793 (1,025—3,275)	3,800 (2,025—5,775)
E9	0.1	1,045 (575—3,775)	1,626 (825—7,275)
E10	0.1	1,153 (525—5,275)	2,379 (750—15,775)
E11	18.5	3,232 (1,275—8,275)	5,978 (1,525—15,775)
	45.75	3,072 (1,525—7,775)	5,135 (1,525—14,525)
E12	0.1	1,499 (775—5,025)	2,603 (1,025—17,275)
E16	61	6,256 (2,025—14,775)	13,649 (8,525—25,775)
E17	61	12,665 (5,025—25,775)	19,689 (11,775—36,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-23. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Sirenians

Range to Effects for Explosives Bin: Sirenians[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	26 (25—45)	109 (85—300)	195 (120—550)
	0.1	20	90 (75—240)	385 (180—975)	646 (250—1,775)
E2	0.1	1	35 (30—40)	164 (100—250)	288 (140—500)
	0.1	2	48 (40—65)	218 (120—370)	375 (170—700)
E3	18.25	1	42 (40—45)	252 (200—460)	532 (370—1,275)
	18.25	50	326 (250—625)	1,595 (800—3,525)	2,985 (1,025—6,775)
E4	15	1	76 (65—100)	513 (450—700)	988 (825—1,275)
	15	5	191 (160—240)	1,080 (925—1,525)	2,118 (1,525—3,275)
	19.8	2	76 (75—80)	461 (400—550)	795 (675—900)
	198	2	0 (0—0)	303 (290—330)	640 (575—775)
E5	0.1	25	280 (150—750)	923 (330—2,775)	1,683 (390—5,525)
E6	0.1	1	95 (75—240)	402 (180—900)	634 (260—1,525)
	30	1	101 (85—120)	697 (550—925)	1,211 (950—2,025)
E7	15	1	199 (190—210)	1,143 (1,025—1,275)	2,254 (1,775—3,025)
E8	0.1	1	156 (100—410)	604 (240—1,525)	937 (340—2,025)
	45.75	1	142 (130—180)	754 (525—1,775)	1,299 (775—3,025)
	305	1	0 (0—12)	620 (600—650)	1,178 (1,025—1,275)
E9	0.1	1	162 (120—290)	638 (290—2,025)	1,033 (400—2,525)

Table 9-23. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Sirenians (Cont'd)

Range to Effects for Explosives Bin: Sirenians[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E10	0.1	1	254 (140—625)	840 (310—2,275)	1,450 (410—4,025)
E11	18.5	1	383 (260—725)	1,728 (800—3,275)	3,231 (1,025—6,525)
	45.75	1	271 (240—400)	1,273 (750—3,025)	2,215 (1,025—5,025)
E12	0.1	1	258 (150—480)	909 (370—2,025)	1,561 (420—6,025)
E16	61	1	720 (625—875)	2,131 (1,275—3,275)	3,118 (1,775—4,775)
E17	61	1	1,073 (800—1,275)	2,998 (1,525—4,525)	4,654 (2,275—14,525)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-24. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Sirenians

Range to Effects for Explosives Bin: Sirenians[1]			
Bin	Source Depth (m)	PTS	TTS
E1	0.1	55 (50—75)	82 (70—150)
E2	0.1	67 (60—85)	110 (80—130)
E3	18.25	148 (120—160)	281 (210—450)
E4	15	200 (190—300)	422 (370—700)
	19.8	193 (190—200)	362 (320—400)
	198	56 (50—60)	293 (290—300)

Table 9-24. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Sirenians (Cont'd)

Range to Effects for Explosives Bin: Sirenians[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E5	0.1	150 (100—240)	252 (130—550)
E6	0.1	201 (110—300)	328 (150—725)
	30	296 (250—360)	560 (410—1,000)
E7	15	569 (470—850)	1,740 (1,275—2,025)
E8	0.1	328 (150—525)	533 (210—2,275)
	45.75	509 (370—1,775)	897 (550—2,025)
	305	435 (430—440)	906 (875—950)
E9	0.1	419 (180—750)	713 (260—4,025)
E10	0.1	484 (200—2,025)	771 (280—5,275)
E11	18.5	1,165 (625—3,275)	2,106 (825—8,025)
	45.75	918 (550—2,525)	1,667 (850—5,025)
E12	0.1	655 (230—3,775)	949 (340—5,025)
E16	61	1,782 (1,025—2,775)	3,514 (1,275—10,025)
E17	61	3,009 (1,275—10,025)	9,174 (2,775—20,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-25. Ranges[1] to Non-Auditory Injury for Sea Turtles as a Function of Animal Mass

Bin	*Animal Mass Intervals (kg)[1]*				
	10	***50***	***100***	***150***	***300***
E1	22 (22—35)	22 (22—35)	22 (22—35)	22 (22—35)	22 (22—35)
E2	25 (25—30)	25 (25—30)	25 (25—30)	25 (25—30)	25 (25—30)
E3	46 (35—75)	46 (35—75)	46 (35—75)	46 (35—75)	46 (35—75)
E4	61 (0—130)	61 (0—130)	61 (0—130)	61 (12—130)	61 (9—130)
E5	76 (55—130)	76 (55—130)	76 (55—130)	76 (55—130)	76 (55—130)
E6	97 (65—390)	97 (65—390)	97 (65—390)	97 (65—390)	97 (65—390)
E7	226 (200—250)	182 (140—210)	182 (140—210)	182 (140—210)	182 (140—210)
E8	170 (0—490)	170 (0—490)	170 (0—490)	170 (25—490)	170 (21—490)
E9	218 (160—400)	218 (160—240)	218 (160—240)	218 (160—240)	218 (160—240)
E10	251 (130—700)	251 (130—370)	251 (130—320)	251 (130—320)	251 (130—320)
E11	589 (410—2,275)	405 (310—1,275)	405 (310—1,025)	405 (310—1,025)	405 (310—1,025)
E12	427 (230—1,025)	339 (230—525)	339 (230—410)	339 (230—390)	339 (230—390)
E16	1,757 (1,275—3,025)	1,757 (1,025—3,025)	1,757 (1,025—3,025)	1,757 (925—3,025)	1,757 (925—3,025)
E17	3,613 (1,275—9,775)	2,346 (1,275—5,525)	2,267 (1,275—5,525)	2,267 (1,275—5,525)	2,267 (1,275—5,525)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-26. Ranges[1] to Mortality for Sea Turtles as a Function of Animal Mass

Bin	*Animal Mass Intervals (kg)[1]*				
	10	***50***	***100***	***150***	***300***
E1	4 (3—5)	2 (2—3)	0 (0—2)	0 (0—2)	0 (0—0)
E2	5 (5—6)	3 (3—4)	3 (2—3)	2 (2—2)	1 (0—2)
E3	11 (9—14)	7 (6—8)	5 (5—6)	4 (4—5)	3 (3—4)
E4	20 (0—40)	12 (0—24)	9 (0—20)	9 (6—18)	6 (4—12)
E5	17 (14—40)	11 (10—25)	9 (8—20)	8 (7—14)	6 (5—10)
E6	25 (18—70)	16 (13—35)	13 (10—30)	12 (9—25)	8 (7—19)
E7	99 (75—120)	57 (45—70)	43 (35—50)	36 (30—45)	25 (24—30)
E8	67 (0—130)	40 (0—80)	31 (0—60)	27 (0—50)	20 (12—30)
E9	54 (40—190)	29 (25—45)	25 (24—25)	22 (21—24)	17 (16—18)
E10	103 (40—300)	44 (30—160)	28 (25—45)	25 (25—40)	21 (19—35)
E11	293 (230—675)	186 (160—300)	147 (130—230)	126 (120—200)	92 (85—140)
E12	189 (60—430)	111 (40—260)	57 (35—200)	40 (30—160)	25 (25—30)
E16	1,055 (1,000—1,525)	883 (750—1,025)	705 (650—800)	628 (600—675)	504 (480—550)
E17	1,699 (1,275—2,525)	1,339 (1,025—2,025)	1,057 (950—1,775)	999 (875—1,025)	924 (800—1,025)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-27. SEL Based Ranges to Onset PTS and Onset TTS

Range to Effects for Explosives Bin: Sea Turtles[1]				
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**
E1	0.1	1	0 (0—0)	0 (0—0)
	0.1	20	0 (0—0)	2 (2—4)
E2	0.1	1	0 (0—0)	0 (0—0)
	0.1	2	0 (0—0)	0 (0—0)
E3	18.25	1	3 (3—3)	17 (16—19)
	18.25	50	25 (23—25)	145 (130—220)
E4	15	1	5 (5—8)	41 (40—50)
	15	5	13 (12—17)	99 (90—110)
	19.8	2	7 (7—7)	50 (50—50)
	198	2	4 (0—7)	18 (0—35)
E5	0.1	25	6 (6—14)	41 (25—160)
E6	0.1	1	2 (2—3)	11 (10—15)
	30	1	16 (13—24)	129 (95—360)
E7	15	1	51 (45—55)	361 (330—390)
E8	0.1	1	6 (5—11)	60 (25—180)
	45.75	1	40 (40—65)	308 (260—725)
	305	1	15 (0—35)	128 (55—190)
E9	0.1	1	9 (9—20)	160 (40—350)

Table 9-27. SEL Based Ranges to Onset PTS and Onset TTS (Cont'd)

Range to Effects for Explosives Bin: Sea Turtles[1]				
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**
E10	0.1	1	15 (13—25)	207 (50—625)
E11	18.5	1	229 (170—440)	1,474 (750—4,025)
	45.75	1	179 (170—260)	1,143 (700—2,775)
E12	0.1	1	25 (18—120)	367 (80—900)
E16	61	1	1,059 (900—1,525)	5,257 (1,525—10,525)
E17	61	1	1,869 (1,275—2,775)	13,443 (7,775—23,275)

[1]Average distance (m) to PTS and TTS are depicted above the minimum and maximum distances which are in parentheses. Values depict the maximum range produced by the SEL metric.

Table 9-28. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Sea Turtles

Range to Effects for Explosives Bin: Sea Turtles[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E1	0.1	36 (30—60)	66 (50—100)
E2	0.1	44 (40—60)	70 (60—85)
E3	18.25	80 (80—110)	152 (140—230)
E4	15	111 (100—180)	220 (190—440)
	19.8	101 (100—110)	198 (190—250)
	198	85 (65—110)	181 (170—220)
E5	0.1	116 (75—140)	210 (100—250)

Table 9-28. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Sea Turtles (Cont'd)

Range to Effects for Explosives Bin: Sea Turtles[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E6	0.1	144 (95—170)	257 (130—320)
	30	218 (160—450)	436 (300—1,275)
E7	15	321 (250—410)	660 (500—850)
E8	0.1	243 (130—320)	403 (190—525)
	45.75	334 (280—775)	696 (500—1,775)
	305	250 (210—310)	508 (490—625)
E9	0.1	350 (230—400)	563 (330—750)
E10	0.1	389 (180—925)	619 (320—1,275)
E11	18.5	715 (480—2,025)	1,350 (800—3,775)
	45.75	761 (525—1,775)	1,399 (925—3,525)
E12	0.1	510 (310—675)	797 (460—2,025)
E16	61	2,500 (1,275—5,775)	3,761 (1,275—9,275)
E17	61	3,097 (1,275—8,275)	4,735 (1,525—10,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

9.2 HSTT Marine Mammals and Reptiles

9.2.1 Impact Ranges for Sonar and Other Transducers

The ranges to the PTS threshold for an exposure of 30 seconds are shown in Table 9-29 and 9-35 relative to a functional hearing group. This period (30 seconds) was chosen based on examining the maximum amount of time a marine mammal would realistically be exposed to levels that could cause the onset of PTS based on platform (e.g., ship) speed and a nominal animal swim speed of approximately 1.5 meters per second. The ranges provided in the table include the average range to PTS, as well as the range from the minimum to the maximum distance at which PTS is possible for each hearing group.

Since any hull-mounted sonar, such as the SQS-53, engaged in antisubmarine warfare training would be moving at between 10–15 knots and nominally pinging every 50 seconds; the vessel will have traveled a minimum distance of approximately 257 m during the time between those pings (note: 10 knots is the speed used in the Navy Acoustic Effects Model). As a result, there is little overlap of PTS footprints from successive pings, indicating that in most cases, an animal predicted to receive PTS would do so from a single exposure (i.e., ping). For all other bins (besides MF1), PTS ranges are short enough that marine mammals (with a nominal swim speed of approximately 1.5 meters per second) should be able to avoid higher sound levels capable of causing onset PTS within this 30-second period.

For all other functional hearing groups (low-frequency cetaceans, mid-frequency cetaceans, and phocid seals and sirenia), 30-second average PTS zones are substantially shorter. A scenario could occur where an animal does not leave the vicinity of a ship or travels a course parallel to the ship, however, the close distances required make PTS exposure unlikely. For a Navy vessel moving at a nominal 10 knots, it is unlikely a marine mammal could maintain the speed to parallel the ship and receive adequate energy over successive pings to suffer PTS.

The tables below illustrate the range to TTS for 1, 30, 60, and 120 seconds from five representative sonar systems (Tables 9-30 through 9-34 and Tables 9-36 through 9-40). Due to the lower acoustic thresholds for TTS versus PTS, ranges to TTS are longer. Therefore, successive pings can be expected to add together, further increasing the range to onset-TTS.

Table 9-29. HSTT Acoustic Ranges to PTS for Marine Mammals

Hearing Group	***Approximate PTS (30 seconds) Ranges (meters)***[1]			
	Sonar bin LF5M	***Sonar bin MF1***	***Sonar bin MF4***	***Sonar bin MF5***
HF Cetacean	0 (0—0)	181 (180—190)	30 (30—30)	9 (8—10)
LF Cetacean	0 (0—0)	65 (65—65)	14 (0—15)	0 (0—0)
MF Cetacean	0 (0—0)	16 (16—16)	3 (3—3)	0 (0—0)
Otariidae	0 (0—0)	6 (6—6)	0 (0—0)	0 (0—0)
Phocinae	0 (0—0)	45 (45—45)	11 (11—11)	0 (0—0)

[1] PTS ranges extend from the sonar or other active acoustic sound source to the indicated distance. The average range to PTS is provided as well as the range from the estimated minimum to the maximum range to PTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-30. HSTT Sonar Bin HF4 Ranges to TTS for Marine Mammals

Hearing Group	Approximate TTS Ranges (meters)[1]			
	Sonar Bin HF4			
	1 second	30 seconds	60 seconds	120 seconds
HF Cetacean	168 (25—550)	280 (55—775)	371 (80—1,275)	470 (100—1,525)
LF Cetacean	1 (0—3)	2 (0—5)	4 (0—7)	6 (0—11)
MF Cetacean	10 (4—17)	17 (6—35)	24 (7—60)	34 (9—90)
Otariidae	0 (0—0)	0 (0—0)	0 (0—0)	1 (0—1)
Phocinae	2 (0—5)	5 (2—8)	8 (3—13)	11 (4—22)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-31. HSTT Sonar Bin LF5M Ranges to TTS for Marine Mammals

Hearing Group	Approximate TTS Ranges (meters)[1]			
	Sonar Bin LF5M			
	1 second	30 seconds	60 seconds	120 seconds
HF Cetacean	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
LF Cetacean	3 (0—4)	3 (0—4)	3 (0—4)	3 (0—4)
MF Cetacean	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
Otariidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
Phocinae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-32. HSTT Sonar Bin MF1 Ranges to TTS for Marine Mammals

Hearing Group	***Approximate TTS Ranges (meters)[1]***			
	Sonar Bin MF1			
	1 second	***30 seconds***	***60 seconds***	***120 seconds***
HF Cetacean	3,043 (1,525—4,775)	3,043 (1,525—4,775)	4,739 (2,025—6,275)	5,614 (2,025—7,525)
LF Cetacean	903 (850—1,025)	903 (850—1,025)	1,264 (1,025—2,275)	1,839 (1,275—3,025)
MF Cetacean	210 (210—210)	210 (210—210)	302 (300—310)	379 (370—390)
Otariidae	65 (65—65)	65 (65—65)	106 (100—110)	137 (130—140)
Phocinae	669 (650—725)	669 (650—725)	970 (900—1,025)	1,075 (1,025—1,525)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-33. HSTT Sonar Bin MF4 Ranges to TTS for Marine Mammals

Hearing Group	***Approximate TTS Ranges (meters)[1]***			
	Sonar Bin MF4			
	1 second	***30 seconds***	***60 seconds***	***120 seconds***
HF Cetacean	240 (220—300)	492 (440—775)	668 (550—1,025)	983 (825—2,025)
LF Cetacean	77 (0—85)	162 (150—180)	235 (220—290)	370 (310—600)
MF Cetacean	22 (22—22)	35 (35—35)	49 (45—50)	70 (70—70)
Otariidae	8 (8—8)	15 (15—15)	19 (19—19)	25 (25—25)
Phocinae	65 (65—65)	110 (110—110)	156 (150—170)	269 (240—460)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-34. HSTT Sonar Bin MF5 Ranges to TTS for Marine Mammals

Hearing Group	Approximate TTS Ranges (meters)[1] Sonar Bin MF5			
	1 second	30 seconds	60 seconds	120 seconds
HF Cetacean	118 (100—170)	118 (100—170)	179 (150—480)	273 (210—700)
LF Cetacean	10 (0—12)	10 (0—12)	14 (0—18)	21 (0—25)
MF Cetacean	6 (0—9)	6 (0—9)	12 (0—13)	17 (0—21)
Otariidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
Phocinae	9 (8—10)	9 (8—10)	14 (14—16)	21 (21—25)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-35. HSTT Acoustic Ranges to PTS for Sea Turtles

Hearing Group	Approximate PTS (30 seconds) Ranges (meters)[1]				
	Sonar bin LF5M	Sonar bin MF1	Sonar bin MF4	Sonar bin MF5	Sonar bin HF4
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] PTS ranges extend from the sonar or other active acoustic sound source to the indicated distance. The average range to PTS is provided as well as the range from the estimated minimum to the maximum range to PTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-36. HSTT Sonar Bin HF4 Ranges to TTS for Sea Turtles

Hearing Group	Approximate TTS Ranges (meters)[1] Sonar Bin HF4			
	1 second	30 seconds	60 seconds	120 seconds
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.

Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-37. HSTT Sonar Bin LF5M Ranges to TTS for Sea Turtles

Hearing Group	*Approximate TTS Ranges (meters)[1]*			
	Sonar Bin LF5M			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.
Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-38. HSTT Sonar Bin MF1 Ranges to TTS for Sea Turtles

Hearing Group	*Approximate TTS Ranges (meters)[1]*			
	Sonar Bin MF1			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.
Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-39. HSTT Sonar Bin MF4 Ranges to TTS for Sea Turtles

Hearing Group	*Approximate TTS Ranges (meters)[1]*			
	Sonar Bin MF4			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.
Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

Table 9-40. HSTT Sonar Bin MF5 Ranges to TTS for Sea Turtles

Hearing Group	*Approximate TTS Ranges (meters)[1]*			
	Sonar Bin MF5			
	1 second	*30 seconds*	*60 seconds*	*120 seconds*
Chelonioidae	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)

[1] Ranges to TTS represent the model predictions in different areas and seasons within the Study Area. The zone in which animals are expected to suffer TTS extend from onset-PTS to the distance indicated. The average range to TTS is provided as well as the range from the estimated minimum to the maximum range to TTS in parentheses.
Notes: HF: high frequency; LF: low frequency; MF: mid-frequency; PTS: permanent threshold shift; TTS: temporary threshold shift

9.2.2 Impact Ranges for Explosives

The following section provides the range (distance) over which specific physiological or behavioral effects are expected to occur based on the explosive criteria (U.S. Department of the Navy, 2017c) and the explosive propagation calculations from the Navy Acoustic Effects Model (U.S. Department of the Navy, 2017d). The ranges to effects are shown for a range of explosive bins, from E1 (up to 0.25 lb net explosive weight) to E12 (up to 1,000 lb net explosive weight). Ranges are determined by modeling the distance that noise from an explosion will need to propagate to reach exposure level thresholds specific to a hearing group that will cause behavioral response, TTS, PTS, and non-auditory injury. Range to effects is important information in not only predicting impacts from explosives, but also in verifying the accuracy of model results against real-world situations and determining adequate mitigation ranges to avoid higher level effects, especially physiological effects to marine mammals.

Tables 9-41 and 9-53 show the minimum, average, and maximum ranges due to varying propagation conditions to non-auditory injury as a function of animal mass and explosive bin (i.e. net explosive weight). These ranges represent the larger of the range to slight lung injury or gastrointestinal tract injury for representative animal masses ranging from 10 to 72,000 kg and different explosive bins ranging from 0.25 to 14,500 lb. net explosive weight. Animals within these water volumes would be expected to receive minor injuries at the outer ranges, increasing to more substantial injuries, and finally mortality (Tables 9-42 and 9-54) as an animal approaches the detonation point.

The following tables (Tables 9-43 through 9-52 and Tables 9-55 through 9-56) show the minimum, average, and maximum ranges to onset of auditory and behavioral effects based on the thresholds described in The Criteria and Thresholds for Assessing Acoustic and Explosive Impacts to Marine Mammals and Sea Turtles technical report (U.S. Department of the Navy, 2017c). Ranges are provided for a representative source depth and cluster size for each bin. For events with multiple explosions, sound from successive explosions can be expected to accumulate and increase the range to the onset of an impact based on SEL thresholds. Modeled ranges to TTS and PTS based on peak pressure for a single explosion generally exceed the modeled ranges based on SEL even when accumulated for multiple explosions. Peak pressure based ranges are estimated using the best available science; however, data on peak pressure at far distances from explosions are very limited. For additional information on how ranges to impacts from explosions were estimated, see the technical report Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing Ranges (U.S. Department of the Navy, 2017d).

Table 9-41. Ranges[1] to Non-Auditory Injury for All Marine Mammal Hearing Groups as a Function of Animal Mass

Bin	Animal Mass Intervals (kg)[1]					
	10	250	1,000	5,000	25,000	72,000
E1	22 (21—24)	22 (21—24)	22 (21—24)	22 (21—24)	22 (21—24)	22 (21—24)
E2	26 (25—30)	26 (25—30)	26 (25—30)	26 (25—30)	26 (25—30)	26 (25—30)
E3	46 (35—65)	46 (35—65)	46 (35—65)	46 (35—65)	46 (35—65)	46 (35—65)
E4	64 (3—130)	64 (0—130)	64 (0—130)	64 (0—130)	64 (0—130)	64 (0—130)
E5	77 (45—190)	77 (45—140)	77 (45—130)	77 (45—130)	77 (45—130)	77 (45—130)
E6	97 (50—270)	97 (50—230)	97 (50—230)	97 (50—230)	97 (50—230)	97 (50—230)
E7	198 (140—575)	172 (140—525)	172 (140—460)	172 (140—460)	172 (140—460)	172 (140—460)
E8	173 (100—450)	173 (100—430)	173 (100—430)	173 (100—430)	173 (100—430)	173 (100—430)
E9	223 (120—430)	223 (120—340)	223 (120—230)	223 (120—230)	223 (120—230)	223 (120—230)
E10	274 (130—700)	274 (130—525)	274 (130—310)	274 (130—310)	274 (130—310)	274 (130—310)
E11	573 (450—2,025)	400 (280—2,025)	400 (280—1,025)	400 (280—1,025)	400 (280—1,025)	400 (280—1,025)
E12	351 (150—1,275)	351 (150—875)	351 (150—400)	351 (150—400)	351 (150—400)	351 (150—400)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-42. Ranges[1] to Mortality Injury for All Marine Mammal Hearing Groups as a Function of Animal Mass

Bin	Animal Mass Intervals (kg)[1]					
	10	250	1,000	5,000	25,000	72,000
E1	4 (3—5)	1 (0—4)	0 (0—0)	0 (0—0)	0 (0—0)	0 (0—0)
E2	5 (5—6)	2 (0—5)	0 (0—2)	0 (0—0)	0 (0—0)	0 (0—0)
E3	11 (9—14)	6 (3—11)	3 (2—4)	1 (0—2)	0 (0—0)	0 (0—0)
E4	21 (0—50)	12 (0—40)	5 (0—12)	3 (0—8)	2 (0—4)	0 (0—3)
E5	18 (14—60)	10 (5—50)	5 (3—16)	3 (2—11)	0 (0—5)	0 (0—4)

Table 9-42. Ranges[1] to Mortality Injury for All Marine Mammal Hearing Groups as a Function of Animal Mass (Cont'd)

Bin	*Animal Mass Intervals (kg)[1]*					
	10	*250*	*1,000*	*5,000*	*25,000*	*72,000*
E6	24 (18—80)	13 (7—60)	6 (4—21)	4 (3—14)	2 (0—6)	0 (0—5)
E7	92 (70—230)	49 (25—190)	22 (16—40)	14 (10—25)	7 (6—13)	5 (4—10)
E8	73 (30—150)	37 (12—120)	17 (7—25)	12 (6—18)	6 (0—8)	5 (2—7)
E9	50 (40—170)	26 (17—120)	14 (11—16)	9 (8—12)	5 (4—5)	4 (3—4)
E10	103 (50—280)	38 (21—220)	17 (14—21)	12 (10—14)	6 (6—8)	5 (4—6)
E11	291 (250—775)	154 (90—600)	66 (55—140)	43 (35—95)	22 (9—40)	18 (15—30)
E12	143 (65—470)	56 (25—350)	22 (18—25)	15 (12—18)	8 (7—9)	6 (5—8)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-43. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for High-Frequency Cetaceans

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	353 (130—825)	1,234 (290—3,025)	2,141 (340—4,775)
	0.1	25	1,188 (280—3,025)	3,752 (490—8,525)	5,196 (675—12,275)
E2	0.1	1	425 (140—1,275)	1,456 (300—3,525)	2,563 (390—5,275)
	0.1	10	988 (280—2,275)	3,335 (480—7,025)	4,693 (650—10,275)
E3	0.1	1	654 (220—1,525)	2,294 (350—4,775)	3,483 (490—7,775)
	0.1	12	1,581 (300—3,525)	4,573 (650—10,275)	6,188 (725—14,775)
	18.25	1	747 (550—1,525)	3,103 (950—6,025)	5,641 (1,000—9,275)
	18.25	12	1,809 (875—4,025)	7,807 (1,025—12,775)	10,798 (1,025—17,775)

Table 9-43. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for High-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E4	3	2	2,020 (1,025—3,275)	3,075 (1,025—6,775)	3,339 (1,025—9,775)
	15.25	2	970 (600—1,525)	4,457 (1,025—8,525)	6,087 (1,275—12,025)
	19.8	2	1,023 (1,000—1,025)	4,649 (2,275—8,525)	6,546 (3,025—11,025)
	198	2	959 (875—1,525)	4,386 (3,025—7,525)	5,522 (3,025—9,275)
E5	0.1	25	2,892 (440—6,275)	6,633 (725—16,025)	8,925 (800—22,775)
	15.25	25	4,448 (1,025—7,775)	10,504 (1,525—18,275)	13,605 (1,775—24,775)
E6	0.1	1	1,017 (280—2,525)	3,550 (490—7,775)	4,908 (675—12,275)
	3	1	2,275 (2,025—2,525)	6,025 (4,525—7,275)	7,838 (6,275—9,775)
	15.25	1	1,238 (625—2,775)	5,613 (1,025—10,525)	7,954 (1,275—14,275)
E7	3	1	3,150 (2,525—3,525)	7,171 (5,525—8,775)	8,734 (7,275—10,525)
	18.25	1	2,082 (925—3,525)	6,170 (1,275—10,525)	8,464 (1,525—16,525)
E8	0.1	1	1,646 (775—2,525)	4,322 (1,525—9,775)	5,710 (1,525—14,275)
	45.75	1	1,908 (1,025—4,775)	5,564 (1,525—12,525)	7,197 (1,525—18,775)
E9	0.1	1	2,105 (850—4,025)	4,901 (1,525—12,525)	6,700 (1,525—16,775)
E10	0.1	1	2,629 (875—5,275)	5,905 (1,525—13,775)	7,996 (1,525—20,025)
E11	18.5	1	3,034 (1,025—6,025)	7,636 (1,525—16,525)	9,772 (1,775—21,525)
	45.75	1	2,925 (1,525—6,025)	7,152 (2,275—18,525)	9,011 (2,525—24,525)

Table 9-43. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for High-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E12	0.1	1	2,868 (975—5,525)	6,097 (2,275—14,775)	8,355 (4,275—21,275)
	0.1	3	3,762 (1,525—8,275)	7,873 (3,775—20,525)	10,838 (4,275—26,525)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-44. Peak Pressure Based Ranges to Onset PTS and Onset TTS for High-Frequency Cetaceans

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]			
Bin	Source Depth (m)	PTS	TTS
E1	0.1	660 (170—1,025)	1,054 (270—1,775)
E2	0.1	806 (190—2,025)	1,280 (300—6,025)
E3	0.1	1,261 (290—6,025)	2,068 (480—9,025)
	18.25	1,615 (925—5,275)	2,813 (1,025—6,775)
E4	3	2,466 (1,025—4,025)	2,823 (1,025—4,275)
	15.25	2,524 (1,025—6,525)	4,955 (1,775—11,025)
	19.8	2,113 (1,275—3,025)	3,570 (1,775—6,275)
	198	3,682 (2,275—7,025)	5,586 (3,025—11,275)
E5	0.1	1,869 (410—7,775)	2,751 (600—13,275)
	15.25	2,908 (1,525—7,775)	5,291 (2,025—11,775)

Table 9-44. Peak Pressure Based Ranges to Onset PTS and Onset TTS for High-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: High-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E6	0.1	2,177 (525—9,275)	3,136 (625—14,025)
	3	2,817 (2,525—3,525)	4,817 (4,025—5,775)
	15.25	4,061 (1,775—11,275)	6,726 (2,025—16,775)
E7	3	4,525 (3,775—5,275)	6,171 (5,525—7,525)
	18.25	5,496 (2,525—12,775)	8,114 (3,025—14,275)
E8	0.1	2,986 (925—5,775)	3,806 (1,525—9,775)
	45.75	4,916 (1,525—13,525)	7,111 (2,275—27,775)
E9	0.1	3,365 (1,275—8,025)	4,409 (1,525—13,525)
E10	0.1	3,791 (1,275—9,775)	5,540 (1,775—26,025)
E11	18.5	10,062 (4,025—23,025)	13,369 (5,025—33,025)
	45.75	7,635 (2,275—31,025)	12,673 (3,775—37,775)
E12	0.1	4,110 (1,525—13,525)	5,603 (2,025—21,775)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-45. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Low-Frequency Cetaceans

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	51 (40—70)	227 (100—320)	124 (70—160)
	0.1	25	205 (95—270)	772 (270—1,275)	476 (190—725)
E2	0.1	1	65 (45—95)	287 (120—400)	159 (80—210)
	0.1	10	176 (85—240)	696 (240—1,275)	419 (160—625)
E3	0.1	1	109 (65—150)	503 (190—1,000)	284 (120—430)
	0.1	12	338 (130—525)	1,122 (320—7,775)	761 (240—6,025)
	18.25	1	205 (170—340)	996 (410—2,275)	539 (330—1,275)
	18.25	12	651 (340—1,275)	3,503 (600—8,275)	1,529 (470—3,275)
E4	3	2	493 (440—1,000)	2,611 (1,025—4,025)	1,865 (950—2,775)
	15.25	2	583 (350—850)	3,115 (1,275—5,775)	1,554 (1,000—2,775)
	19.8	2	378 (370—380)	1,568 (1,275—1,775)	926 (825—950)
	198	2	299 (290—300)	2,661 (1,275—3,775)	934 (900—950)
E5	0.1	25	740 (220—6,025)	2,731 (460—22,275)	1,414 (350—14,275)
	15.25	25	1,978 (1,025—5,275)	8,188 (3,025—19,775)	4,727 (1,775—11,525)
E6	0.1	1	250 (100—420)	963 (260—7,275)	617 (200—1,275)
	3	1	711 (525—825)	3,698 (1,525—4,275)	2,049 (1,025—2,525)
	15.25	1	718 (390—2,025)	3,248 (1,275—8,525)	1,806 (950—4,525)

Table 9-45. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Low-Frequency Cetaceans (cont'd)

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E7	3	1	1,121 (850—1,275)	5,293 (2,025—6,025)	3,305 (1,275—4,025)
	18.25	1	1,889 (1,025—2,775)	6,157 (2,775—11,275)	4,103 (2,275—7,275)
E8	0.1	1	460 (170—950)	1,146 (380—7,025)	873 (280—3,025)
	45.75	1	1,049 (550—2,775)	4,100 (1,025—14,275)	2,333 (800—7,025)
E9	0.1	1	616 (200—1,275)	1,560 (450—12,025)	1,014 (330—5,025)
E10	0.1	1	787 (210—2,525)	2,608 (440—18,275)	1,330 (330—9,025)
E11	18.5	1	4,315 (2,025—8,025)	10,667 (4,775—26,775)	7,926 (3,275—21,025)
	45.75	1	1,969 (775—5,025)	9,221 (2,525—29,025)	4,594 (1,275—16,025)
E12	0.1	1	815 (250—3,025)	2,676 (775—18,025)	1,383 (410—8,525)
	0.1	3	1,040 (330—6,025)	4,657 (1,275—31,275)	2,377 (700—16,275)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-46. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Low-Frequency Cetaceans

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E1	0.1	126 (55—140)	226 (90—270)
E2	0.1	161 (65—180)	280 (100—340)

Table 9-46. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Low-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E3	0.1	264 (100—320)	453 (140—600)
	18.25	330 (240—875)	614 (330—1,775)
E4	3	531 (420—625)	916 (650—2,025)
	15.25	525 (350—725)	864 (550—1,275)
	19.8	390 (370—400)	730 (650—800)
	198	379 (340—400)	746 (675—1,525)
E5	0.1	404 (130—525)	679 (180—1,025)
	15.25	547 (360—1,275)	991 (675—1,525)
E6	0.1	496 (150—700)	797 (210—6,025)
	3	817 (650—975)	1,317 (1,025—1,775)
	15.25	735 (420—1,275)	1,266 (875—2,525)
E7	3	1,017 (925—1,025)	1,977 (1,775—2,275)
	18.25	1,246 (875—1,775)	2,368 (1,525—3,775)
E8	0.1	830 (260—1,275)	1,045 (360—1,775)
	45.75	1,306 (550—3,775)	2,008 (675—6,025)

Table 9-46. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Low-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Low-Frequency Cetaceans[1]			
Bin	Source Depth (m)	PTS	TTS
E9	0.1	966 (310—1,525)	1,240 (420—2,525)
E10	0.1	1,057 (330—1,775)	1,447 (450—6,025)
E11	18.5	2,945 (1,025—7,525)	5,497 (2,025—12,525)
	45.75	2,023 (700—6,775)	2,779 (775—11,275)
E12	0.1	1,155 (390—2,025)	1,512 (550—3,775)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-47. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Mid-Frequency Cetaceans

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E1	0.1	1	25 (25—25)	118 (80—210)	178 (100—320)
	0.1	25	107 (75—170)	476 (150—1,275)	676 (240—1,525)
E2	0.1	1	30 (30—35)	145 (95—240)	218 (110—400)
	0.1	10	88 (65—130)	392 (140—825)	567 (190—1,275)
E3	0.1	1	50 (45—65)	233 (110—430)	345 (130—600)
	0.1	12	153 (90—250)	642 (220—1,525)	897 (270—2,025)
	18.25	1	38 (35—40)	217 (190—900)	331 (290—850)
	18.25	12	131 (120—250)	754 (550—1,525)	1,055 (600—2,525)

Table 9-47. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Mid-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E4	3	2	139 (110—160)	1,069 (525—1,525)	1,450 (875—1,775)
	15.25	2	71 (70—75)	461 (400—725)	613 (470—750)
	19.8	2	69 (65—70)	353 (350—360)	621 (600—650)
	198	2	49 (0—55)	275 (270—280)	434 (430—440)
E5	0.1	25	318 (130—625)	1,138 (280—3,025)	1,556 (310—3,775)
	15.25	25	312 (290—725)	1,321 (675—2,525)	1,980 (850—4,275)
E6	0.1	1	98 (70—170)	428 (150—800)	615 (210—1,525)
	3	1	159 (150—160)	754 (650—850)	1,025 (1,025—1,025)
	15.25	1	88 (75—180)	526 (450—875)	719 (500—1,025)
E7	3	1	240 (230—260)	1,025 (1,025—1,025)	1,900 (1,775—2,275)
	18.25	1	166 (120—310)	853 (500—1,525)	1,154 (550—1,775)
E8	0.1	1	160 (150—170)	676 (500—725)	942 (600—1,025)
	45.75	1	128 (120—170)	704 (575—2,025)	1,040 (750—2,525)
E9	0.1	1	215 (200—220)	861 (575—950)	1,147 (650—1,525)
E10	0.1	1	275 (250—480)	1,015 (525—2,275)	1,424 (675—3,275)
E11	18.5	1	335 (260—500)	1,153 (650—1,775)	1,692 (775—3,275)
	45.75	1	272 (230—825)	1,179 (825—3,025)	1,784 (1,000—4,275)

Table 9-47.SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Mid-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E12	0.1	1	334 (310—350)	1,151 (700—1,275)	1,541 (800—3,525)
	0.1	3	520 (450—550)	1,664 (800—3,525)	2,195 (925—4,775)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-48. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Mid-Frequency Cetaceans

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]			
Bin	Source Depth (m)	PTS	TTS
E1	0.1	43 (35—45)	81 (45—95)
E2	0.1	57 (40—65)	102 (50—110)
E3	0.1	96 (50—110)	174 (65—210)
	18.25	101 (100—130)	196 (180—725)
E4	3	261 (180—300)	421 (250—460)
	15.25	162 (120—290)	328 (240—725)
	19.8	120 (120—120)	240 (240—240)
	198	117 (80—120)	229 (210—230)
E5	0.1	149 (65—160)	272 (95—300)
	15.25	178 (160—430)	358 (290—825)

Table 9-48. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Mid-Frequency Cetaceans (Cont'd)

Range to Effects for Explosives Bin: Mid-Frequency Cetaceans[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E6	0.1	188 (70—230)	338 (110—400)
	3	268 (230—360)	527 (410—625)
	15.25	240 (200—460)	479 (400—725)
E7	3	459 (320—625)	730 (575—900)
	18.25	429 (310—550)	676 (550—800)
E8	0.1	337 (300—370)	580 (400—750)
	45.75	431 (340—1,025)	806 (600—2,275)
E9	0.1	450 (350—525)	757 (450—1,025)
E10	0.1	534 (240—700)	902 (410—1,275)
E11	18.5	896 (725—1,025)	1,577 (1,025—2,275)
	45.75	824 (600—2,775)	1,484 (900—4,775)
E12	0.1	669 (430—925)	1,074 (525—1,525)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-49. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Otariids

Range to Effects for Explosives Bin: Otariids[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E1	0.1	1	7 (7—7)	34 (30—40)	56 (45—70)
	0.1	25	30 (25—35)	136 (80—180)	225 (100—320)
E2	0.1	1	9 (9—9)	41 (35—55)	70 (50—95)
	0.1	10	25 (25—30)	115 (70—150)	189 (95—250)
E3	0.1	1	16 (15—19)	70 (50—95)	115 (70—150)
	0.1	12	45 (35—65)	206 (100—290)	333 (130—450)
	18.25	1	15 (15—15)	95 (90—100)	168 (150—310)
	18.25	12	55 (50—60)	333 (280—750)	544 (440—1,025)
E4	3	2	64 (40—85)	325 (240—340)	466 (370—490)
	15.25	2	30 (30—35)	205 (170—300)	376 (310—575)
	19.8	2	25 (25—25)	170 (170—170)	290 (290—290)
	198	2	17 (0—25)	117 (110—120)	210 (210—210)
E5	0.1	25	98 (60—120)	418 (160—575)	626 (240—1,000)
	15.25	25	151 (140—260)	750 (650—1,025)	1,156 (975—2,025)
E6	0.1	1	30 (25—35)	134 (75—180)	220 (100—320)
	3	1	53 (50—55)	314 (280—390)	459 (420—525)
	15.25	1	36 (35—40)	219 (200—380)	387 (340—625)

Table 9-49. SEL Based Ranges to Onset PTS, Onset TTS, and Behavioral Reaction for Otariids (Cont'd)

Range to Effects for Explosives Bin: Otariids[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E7	3	1	93 (90—100)	433 (380—500)	642 (550—800)
	18.25	1	73 (70—75)	437 (360—525)	697 (600—850)
E8	0.1	1	50 (50—50)	235 (220—250)	385 (330—450)
	45.75	1	55 (55—60)	412 (310—775)	701 (500—1,525)
E9	0.1	1	68 (65—70)	316 (280—360)	494 (390—625)
E10	0.1	1	86 (80—95)	385 (240—460)	582 (390—800)
E11	18.5	1	158 (150—200)	862 (750—975)	1,431 (1,025—2,025)
	45.75	1	117 (110—130)	756 (575—1,525)	1,287 (950—2,775)
E12	0.1	1	104 (100—110)	473 (370—575)	709 (480—1,025)
	0.1	3	172 (170—180)	694 (480—1,025)	924 (575—1,275)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-50. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Otariids

Range to Effects for Explosives Bin: Otariids[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E1	0.1	35 (30—40)	64 (40—95)
E2	0.1	45 (35—50)	82 (45—95)

Table 9-50. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Otariids (Cont'd)

Range to Effects for Explosives Bin: Otariids[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E3	0.1	77 (45—95)	133 (60—150)
	18.25	81 (80—100)	163 (150—480)
E4	3	175 (130—210)	375 (220—410)
	15.25	114 (100—190)	252 (190—420)
	19.8	100 (100—100)	190 (190—190)
	198	98 (95—100)	187 (180—190)
E5	0.1	117 (55—130)	212 (80—250)
	15.25	144 (130—310)	278 (240—725)
E6	0.1	148 (65—170)	263 (95—310)
	3	215 (190—260)	463 (330—625)
	15.25	191 (170—410)	386 (310—825)
E7	3	355 (260—500)	614 (490—750)
	18.25	439 (330—550)	628 (575—675)
E8	0.1	272 (260—280)	482 (370—525)
	45.75	401 (280—950)	770 (500—1,775)
E9	0.1	368 (320—400)	610 (420—800)
E10	0.1	442 (230—525)	715 (330—1,025)

Table 9-50. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Otariids (Cont'd)

Range to Effects for Explosives Bin: Otariids[1]			
Bin	Source Depth (m)	PTS	TTS
E11	18.5	765 (625—1,000)	1,342 (950—2,025)
	45.75	811 (525—2,025)	1,498 (850—3,525)
E12	0.1	550 (400—700)	881 (500—1,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-51. SEL Based Ranges to PTS, TTS, and Behavioral Reaction for Phocids

Range to Effects for Explosives Bin: Phocids[1]					
Bin	Source Depth (m)	Cluster Size	PTS	TTS	Behavioral
E1	0.1	1	45 (40—65)	210 (100—290)	312 (130—430)
	0.1	25	190 (95—260)	798 (280—1,275)	1,050 (360—2,275)
E2	0.1	1	58 (45—75)	258 (110—360)	383 (150—550)
	0.1	10	157 (85—240)	672 (240—1,275)	934 (310—1,525)
E3	0.1	1	96 (60—120)	419 (160—625)	607 (220—900)
	0.1	12	277 (120—390)	1,040 (370—2,025)	1,509 (525—6,275)
	18.25	1	118 (110—130)	621 (500—1,275)	948 (700—2,025)
	18.25	12	406 (330—875)	1,756 (1,025—4,775)	3,302 (1,025—6,275)

Table 9-51. SEL Based Ranges to PTS, TTS, and Behavioral Reaction for Phocids (Cont'd)

Range to Effects for Explosives Bin: Phocids[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E4	3	2	405 (300—430)	1,761 (1,025—2,775)	2,179 (1,025—3,275)
	15.25	2	265 (220—430)	1,225 (975—1,775)	1,870 (1,025—3,275)
	19.8	2	220 (220—220)	991 (950—1,025)	1,417 (1,275—1,525)
	198	2	150 (150—150)	973 (925—1,025)	2,636 (2,025—3,525)
E5	0.1	25	569 (200—850)	2,104 (725—9,275)	2,895 (825—11,025)
	15.25	25	920 (825—1,525)	5,250 (2,025—10,275)	7,336 (2,275—16,025)
E6	0.1	1	182 (90—250)	767 (270—1,275)	1,011 (370—1,775)
	3	1	392 (340—440)	1,567 (1,275—1,775)	2,192 (2,025—2,275)
	15.25	1	288 (250—600)	1,302 (1,025—3,275)	2,169 (1,275—5,775)
E7	3	1	538 (450—625)	2,109 (1,775—2,275)	2,859 (2,775—3,275)
	18.25	1	530 (460—750)	2,617 (1,025—4,525)	3,692 (1,525—5,275)
E8	0.1	1	311 (290—330)	1,154 (625—1,275)	1,548 (725—2,275)
	45.75	1	488 (380—975)	2,273 (1,275—5,275)	3,181 (1,525—8,025)
E9	0.1	1	416 (350—470)	1,443 (675—2,025)	1,911 (800—3,525)
E10	0.1	1	507 (340—675)	1,734 (725—3,525)	2,412 (800—5,025)
E11	18.5	1	1,029 (775—1,275)	5,044 (2,025—8,775)	6,603 (2,525—14,525)
	45.75	1	881 (700—2,275)	3,726 (2,025—8,775)	5,082 (2,025—13,775)

Table 9-51. SEL Based Ranges to PTS, TTS, and Behavioral Reaction for Phocids (Cont'd)

Range to Effects for Explosives Bin: Phocids[1]					
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**	**Behavioral**
E12	0.1	1	631 (450—750)	1,927 (800—4,025)	2,514 (925—5,525)
	0.1	3	971 (550—1,025)	2,668 (1,025—6,275)	3,541 (1,775—9,775)

[1]Average distance (m) to PTS, TTS, and behavioral thresholds are depicted above the minimum and maximum distances which are in parentheses. Values depict the range produced by SEL hearing threshold criteria levels.

Table 9-52. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Phocids

Range to Effects for Explosives Bin: Phocids[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E1	0.1	144 (60—160)	258 (95—300)
E2	0.1	180 (70—220)	323 (110—370)
E3	0.1	303 (100—350)	533 (150—675)
	18.25	373 (270—950)	697 (470—1,775)
E4	3	548 (470—700)	1,230 (675—2,525)
	15.25	567 (460—750)	927 (675—1,525)
	19.8	459 (440—480)	823 (800—900)
	198	431 (420—440)	864 (800—1,000)
E5	0.1	469 (140—600)	815 (190—6,025)
	15.25	604 (550—900)	1,061 (725—1,775)

Table 9-52. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Phocids (Cont'd)

Range to Effects for Explosives Bin: Phocids[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E6	0.1	582 (160—775)	910 (230—6,025)
	3	888 (750—1,025)	1,484 (1,025—1,775)
	15.25	822 (650—1,525)	1,426 (875—2,775)
E7	3	1,109 (1,025—1,525)	2,109 (1,775—2,525)
	18.25	1,482 (1,025—2,025)	2,766 (1,775—4,775)
E8	0.1	987 (500—1,275)	1,472 (625—2,025)
	45.75	1,695 (800—4,525)	2,896 (1,275—8,025)
E9	0.1	1,207 (550—1,525)	1,790 (700—3,025)
E10	0.1	1,407 (450—3,275)	2,043 (775—5,275)
E11	18.5	3,311 (1,775—7,025)	5,848 (2,275—12,525)
	45.75	3,053 (1,525—8,275)	4,178 (1,775—11,275)
E12	0.1	1,580 (675—2,525)	2,228 (825—3,775)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-53. Ranges[1] to Non-Auditory Injury for Sea Turtles as a Function of Animal Mass

Bin	*Animal Mass Intervals (kg)[1]*	
	10	***150***
E1	22 (21—24)	22 (21—24)
E2	26 (25—30)	26 (25—30)
E3	46 (35—65)	46 (35—65)
E4	62 (0—130)	62 (0—130)
E5	77 (45—170)	77 (45—130)
E6	98 (50—230)	98 (50—230)
E7	190 (140—550)	173 (140—460)
E8	173 (160—430)	173 (160—430)
E9	225 (220—380)	225 (220—230)
E10	278 (140—600)	278 (140—310)
E11	544 (460—2,025)	399 (320—1,025)
E12	354 (320—1,025)	354 (320—400)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-54. Ranges[1] to Mortality for Sea Turtles as a Function of Animal Mass

Bin	*Animal Mass Intervals (kg)[1]*	
	10	***150***
E1	4 (3—4)	0 (0—2)
E2	5 (5—6)	2 (2—2)
E3	11 (9—12)	4 (4—5)
E4	20 (0—45)	9 (0—16)

Table 9-54. Ranges[1] to Mortality for Sea Turtles as a Function of Animal Mass (Cont'd)

Bin	*Animal Mass Intervals (kg)[1]*	
	10	***150***
E5	17 (14—55)	8 (7—24)
E6	23 (19—70)	11 (9—30)
E7	89 (75—200)	36 (30—60)
E8	69 (30—140)	28 (16—35)
E9	45 (40—140)	22 (22—23)
E10	96 (50—240)	25 (25—25)
E11	277 (250—600)	122 (120—190)
E12	131 (65—400)	36 (30—80)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

Table 9-55. SEL Based Ranges to Onset PTS and TTS for Sea Turtles

Range to Effects for Explosives Bin: Sea Turtles[1]				
Bin	**Source Depth (m)**	**Cluster Size**	**PTS**	**TTS**
E1	0.1	1	0 (0—0)	0 (0—0)
	0.1	25	0 (0—0)	2 (2—5)
E2	0.1	1	0 (0—0)	0 (0—2)
	0.1	10	0 (0—0)	3 (2—3)
E3	0.1	1	0 (0—0)	3 (2—3)
	0.1	12	1 (0—2)	8 (8—25)
	18.25	1	3 (3—3)	17 (16—18)
	18.25	12	1 (0—2)	8 (8—25)

Table 9-55. SEL Based Ranges to Onset PTS and TTS for Sea Turtles (Cont'd)

Range to Effects for Explosives Bin: Sea Turtles[1]				
Bin	Source Depth (m)	Cluster Size	PTS	TTS
E4	3	2	17 (11—18)	57 (50—70)
	15.25	2	8 (7—9)	63 (55—70)
	19.8	2	7 (7—7)	50 (50—50)
	198	2	0 (0—0)	0 (0—0)
E5	0.1	25	6 (6—25)	45 (25—280)
	15.25	25	59 (55—75)	349 (240—950)
E6	0.1	1	2 (2—2)	10 (10—45)
	3	1	30 (30—30)	143 (140—150)
	15.25	1	17 (15—25)	133 (100—360)
E7	3	1	55 (55—55)	273 (230—360)
	18.25	1	52 (45—90)	526 (330—750)
E8	0.1	1	5 (5—8)	44 (25—280)
	45.75	1	40 (40—50)	289 (260—975)
E9	0.1	1	9 (9—35)	91 (40—525)
E10	0.1	1	13 (13—90)	189 (50—850)
E11	18.5	1	314 (240—525)	2,105 (1,525—2,525)
	45.75	1	171 (170—200)	879 (700—2,275)

Table 9-55. SEL Based Ranges to Onset PTS and TTS for Sea Turtles (Cont'd)

Range to Effects for Explosives Bin: Sea Turtles[1]				
Bin	Source Depth (m)	Cluster Size	PTS	TTS
E12	0.1	1	32 (18—170)	273 (80—1,275)

[1]Average distance (m) to PTS and TTS are depicted above the minimum and maximum distances which are in parentheses. Values depict ranges to PTS and TTS based on the SEL metric.

Table 9-56. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Sea Turtles

Range to Effects for Explosives Bin: Sea Turtles[1]			
Bin	Source Depth (m)	PTS	TTS
E1	0.1	35 (30—40)	66 (40—95)
E2	0.1	46 (35—50)	85 (45—95)
E3	0.1	79 (45—95)	140 (60—150)
	18.25	80 (80—100)	158 (150—480)
E4	3	175 (130—210)	375 (220—410)
	15.25	114 (100—190)	252 (190—420)
	19.8	100 (100—100)	190 (190—190)
	198	75 (75—75)	170 (170—170)
E5	0.1	122 (55—130)	223 (80—250)
	15.25	144 (130—310)	278 (240—725)
E6	0.1	154 (65—170)	278 (95—320)
	3	215 (190—260)	463 (330—625)
	15.25	197 (170—410)	396 (310—825)

Table 9-56. Peak Pressure Based Ranges to Onset PTS and Onset TTS for Sea Turtles (Cont'd)

Range to Effects for Explosives Bin: Sea Turtles[1]			
Bin	**Source Depth (m)**	**PTS**	**TTS**
E7	3	355 (260—500)	614 (490—750)
	18.25	376 (260—550)	587 (470—675)
E8	0.1	276 (260—300)	476 (370—575)
	45.75	348 (280—950)	658 (500—1,775)
E9	0.1	370 (320—420)	620 (420—825)
E10	0.1	439 (230—550)	725 (330—1,025)
E11	18.5	765 (625—1,000)	1,342 (950—2,025)
	45.75	657 (525—1,775)	1,096 (825—3,025)
E12	0.1	548 (400—700)	925 (500—1,275)

[1] Distances in meters (m). Average distance is shown with the minimum and maximum distances due to varying propagation environments in parentheses.

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